

**Effect of Sucrose Reinforcement on Operant Wheel Running on a Fixed Ratio  
Schedule**

BY

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A thesis submitted to the  
Department of Psychology  
Mount Allison University

In partial fulfillment of the requirements for the  
Bachelor of Sciences degree with Honours in Psychology

April 21, 2021

### **Abstract**

In the current study, I investigated the effect of sucrose reinforcement on operant wheel-running on a fixed ratio (FR) schedule. Rats responded on a FR-40 schedule in which wheel-running produced the opportunity to consume sucrose solution. Sucrose reinforcement was removed after 25 sessions and rats were returned to baseline (water). Based on the traditional concept of reinforcement, wheel-running rates were expected to increase close in time before sucrose reinforcement was delivered. Alternatively, there could be a marked increase in running at the beginning due to a schedule-induced effect of sucrose presentation. Results were not consistent with either prediction. Sucrose reinforcement systematically increased running over the entire 40 revolutions. Possible explanations for this extended reinforcement effect are that wheel running, unlike other operant behaviors, such as lever pressing, generates its own automatic reinforcement effect and is a continuous, rather than a discrete, behavior. Further research is required to explore these aspects of wheel running.

## Table of Contents

Title Page .....	i
Abstract .....	ii
Table of Contents .....	iii
List of Figures .....	iv
List of Tables.....	iv
Acknowledgements .....	v
Introduction .....	1
Method .....	10
Subjects .....	10
Apparatus .....	11
Procedure.....	12
Dependent Measures .....	13
Calculated Values.....	13
Results .....	14
Discussion .....	20
References .....	29
Appendix A .....	36
Appendix B .....	37
Appendix C .....	38
Appendix D .....	39
Appendix E .....	40

## List of Tables

Table 1	Operant wheel-running rate (revolutions/min) for the Water 1, Sucrose, and Water 2 conditions for each rat .....	36
Table 2	Average PRP per reinforcer (s) for the Water 1, Sucrose, and Water 2 conditions for each rat .....	37
Table 3	Average wheel-running rates (revolutions/min) across successive sets of five revolutions for the Water 1, Sucrose, and Water 2 conditions for each rat .....	38
Table 4	Average wheel-running rates (revolutions/min) for each reinforcer within a session for the Water 1, Sucrose, and Water 2 conditions for each rat.....	39
Table 5	Average PRP (s) for each reinforcer within a session for the Water 1, Sucrose, and Water 2 conditions for each rat.....	40

## List of Figures

Figure 1	Average wheel-running rates across all subjects for Water 1, Sucrose, and Water 2.....	14
Figure 2	Average PRPs across all subjects for Water 1, Sucrose, and Water 2 .....	15
Figure 3	Average wheel-running rates for Water 1, Sucrose, and Water 2 shown for each 5-revolution bin .....	17
Figure 4	Average wheel-running rates for Water 1, Sucrose, and Water 2 shown for each reinforcement .....	19

## Acknowledgements

First and foremost, I would like to extend my appreciation to Dr. Belke. He has been a patient supervisor, and willingly offered his insight whenever I asked. The completion of this thesis would not have been possible without his feedback. I would also like to thank my second reader, Dr. Wasyliw for being so kind to me and providing her statistics expertise. She ensured that I had a solid understanding of the tests I needed to conduct, and for that I am grateful. I would like to thank Dr. Gould for offering up her time to meet with me, as this was a large factor in understanding myself and deciding what I wanted for my future.

Special thanks goes to Jackie for being a bright presence and good conversationalist during my sessions in the lab. She was always nearby and helped make sure that data collection ran smoothly. As well as Jackie, I am extremely grateful for my lab partner Craig. He assisted me multiple times in the lab and was unquestionably reliable. Talking to him assured me that I was not alone in an atmosphere that other honours students were not participating in.

Finally, I would like to thank my roommates for their support through this study, and my friends and family for supporting me throughout all of my years of study. Due to the pandemic, I did not get to develop many close relationships from the honours class, but I enjoyed our meetings and wish everyone the best.

## **Effect of Sucrose Reinforcement on Operant Wheel Running on a Fixed Ratio Schedule**

Wheel running is a behaviour that can function as a reinforcing consequence or as an operant behaviour. As a reinforcing consequence, wheel running has been extensively investigated (e.g., Belke, 1996, 1997, 2000, 2004, 2007; Belke & Hancock, 2003; Belke & Pierce, 2016; Belke et al., 2004; Belke & Wagner, 2005; Collier & Hirsch, 1971; Iversen, 1993; Kagan & Berkun, 1954; Premack, 1962, Premack et al., 1964). By contrast, far less research has been conducted on wheel running as an operant behaviour (Belke & Pierce, 2014, 2015; Belke et. al., 2015, 2017, 2018; Iso, 1996; Skinner & Morse, 1958). As an operant behaviour, the delivery of a reinforcing consequence such as sugar water is delivered contingent upon wheel running. That is, the first revolution that meets the reinforcement schedule led to the delivery of a reinforcing consequence – whether that is food (Iso, 1996; Skinner & Morse, 1958), or sugar water (Belke & Pierce, 2014, 2015; Belke et. al., 2017). Previous studies have shown that when wheel running was reinforced with sugar water, wheel-running rate increased (Belke et al., 2015; Belke & Pierce, 2014, 2015; Belke et. al., 2017). In other words, sucrose reinforcement reinforced operant wheel running.

Recent research by Belke et al. (2021) however, casts doubt on these studies purporting to show a reinforcement effect on operant wheel running. Their study investigated operant running by rats on a fixed interval (FI) 180-s schedule with increasing concentrations of sucrose (i.e., 0% 5%, 15%, and 25%) as reinforcement. Surprisingly, their results showed that sucrose systematically increased wheel running at the beginning of the fixed interval schedule following the delivery of reinforcement

rather than just prior to reinforcement. This contradicts the traditional concept of reinforcement. According to the response strengthening hypothesis of reinforcement, “any response that closely precedes a reinforcer is strengthened” (Shahan, 2017, p. 112). This finding raises the question of how the operant wheel running was increased by sucrose reinforcement in the prior studies (Belke et al., 2015; Belke & Pierce, 2015; Belke et. al., 2017). Did operant running increase prior to the delivery of sucrose or did it increase following the delivery of sucrose? Since the previous studies that showed a reinforcement effect on operant wheel running used ratio rather than interval schedules, the goal of the current study was to determine when this reinforcing effect was occurring on a fixed ratio (FR) schedule. In other words, we aimed to see if wheel-running rate increased before or after the rats received sucrose.

Skinner and Morse (1958) conducted the first study of operant wheel running by two rats on a FI 5-min schedule of reinforcement with food pellets as reinforcement. Rats were allowed to run freely in a wheel for 30 min prior to and after the FI schedule. During these 30 min periods, the chamber in which the wheel was located was dark. When the FI schedule was in effect, a 6-watt lightbulb illuminated the chamber. After a fixed number of food pellets (e.g., 50, then 40, then 20 pellets) were delivered, the FI schedule terminated. Skinner and Morse (1958) were particularly interested in the pattern of operant wheel revolutions on the FI schedule. To this end, in their cumulative records, they noted a few occurrences of pauses following delivery of food, then acceleration of running followed by an unexpected decline in running just prior to the delivery of reinforcement. Skinner and Morse (1958, p. 375) concluded that “in some instances, responding during the period of fixed-interval reinforcement resembles that

obtained when a rat presses a lever on a fixed-interval schedule”. Although there was no direct assessment of a reinforcing effect of the food reinforcement on operant wheel running, it can readily be seen in the cumulative records that wheel-running rate while the FI schedule was in effect was higher than during the preceding and subsequent 30 min free running periods without reinforcement.

Years later, Iso (1996), investigated operant wheel running on FI and FR schedules under two different levels of food deprivation. In their first experiment they put three rats on a FR-40 schedule and three on a FI 60-s schedule. The operant response was  $\frac{1}{4}$  of a wheel turn and the reinforcement was a 45 mg food pellet. Six control rats were yoked to each of the rats on the FR and FI schedules. The yoked rats received food when their experimental counterparts did. All rats were maintained at 75% of free feeding body weight. After completing sessions on the reinforcement schedules, all rats were placed on extinction. According to Iso (1996), cumulative records for rats on the FR schedule suggested the presence of typical response curves; however, for the FI schedule, only the rat that ran at a lower rate showed evidence for a typical FI schedule response pattern. More importantly, running by rats on the reinforcement schedules did not differ significantly from that of yoked controls. In other words, there was no evidence that food reinforced operant wheel running. Furthermore, consistent with this lack of a reinforcement effect, running did not decline in extinction.

In a second experiment, Iso (1996) repeated the first experiment with eight rats at 90% (rather than 75%) of their free feeding body weight, but with no yoked controls. Four rats responded on a FR 40 schedule and four on a FI 60-s schedule. FR rats showed a typical FR response curve with longer post-reinforcement pauses than in Experiment

1, while rats on the FI schedule were more likely to show a typical “scallop” pattern of responding in cumulative records. In extinction, running appeared to decline, but the difference between running in the last sessions on the FI and FR schedules and the first sessions on extinction was not significant. In summary, although Iso found evidence for response patterns typically observed with FR and FI schedules, neither the comparisons with yoked rats nor running in extinction showed evidence that food served to reinforce wheel running.

Following this research, Belke and Pierce (2014) investigated wheel running as both a reinforcing consequence and an operant behaviour using a multiple schedule. In one component of the multiple schedule, wheel running was an operant behaviour reinforced by sugar water. In the other, it was a reinforcer for lever pressing. In one of the manipulations, the 15% sucrose delivered as reinforcement for operant wheel running was reduced to 0% sucrose (water) then reinstated. When they removed the sucrose, the rate of wheel running in the operant component decreased. When the sucrose was reinstated, the operant wheel running increased back to its prior level. Interestingly, the removal of sucrose from the operant wheel-running component also decreased wheel running in the wheel running as reinforcement component, although the decrease was less than that observed for operant wheel running. In this case, sucrose reinforcement clearly affected operant wheel running to a greater extent than it did wheel running as a reinforcement and the systematic change in operant wheel running rates is consistent with a reinforcement effect. With respect to a direct comparison between operant wheel-running rates and reinforcement wheel-running rates, however, there was no significant difference. In other words, the delivery of sucrose as an

extrinsic reinforcement for operant wheel running did not produce higher wheel-running rates. Belke and Pierce (2014) attributed the lack of evidence for higher operant wheel-running rates to the use of a non-standard multiple schedule on which the advancement of the schedule between components was dependent upon the behaviour of a rat rather than independent of it. In their subsequent study, Belke and Pierce (2015), this issue was corrected.

Belke and Pierce (2015), conducted a follow-up study where they used the same multiple schedule with the exception that the multiple schedule advanced based on time rather than behaviour. As in Belke and Pierce (2014), sucrose concentration was manipulated between 15% and 0%. Operant wheel-running rates and reinforcement wheel-running rates both systematically decreased, increased, and then decreased as sucrose was removed, reinstated, and removed. The manipulation as previously observed, had a greater impact on operant wheel-running rates and, in this case, wheel-running rates in the operant component were significantly higher than those in the wheel running as reinforcement component. Therefore, in this case, sucrose as an extrinsic reinforcement systematically reinforced wheel running through both systematic changes in operant wheel-running rates when sucrose was presented and removed as well as producing higher operant wheel-running rates than reinforcement wheel-running rates.

Belke et al. (2015) conducted a similar study that same year to see the effect of extinction (i.e., a change from 15% to 0% sucrose) on response rates when operant behaviour in one of the components was wheel running versus lever pressing. The procedure used the same multiple schedule as Belke and Pierce (2015) with the exception that in one condition wheel running was the operant behaviour that produced

sucrose reinforcement; in the other condition, lever pressing was the operant that produced sucrose. In both conditions, the alternative component involved wheel running as reinforcement for operant lever pressing. The manipulation was to switch between 15% sucrose and 0% sucrose (water) in the components with operant wheel running and operant lever pressing for sucrose. Results showed that when sucrose was removed for operant wheel running, the wheel-running rate decreased from 58.8 revolutions/min to 44.1 revolutions/min – a 24% decrease. By contrast when sucrose was removed for operant lever pressing, lever-pressing rates decreased from 229 presses/min to 19.3 presses/min – a 90% reduction. As previously observed, operant wheel-running rates systematically decreased when sucrose reinforcement was removed and wheel-running rates in the operant wheel-running component were significantly higher than wheel-running rates in the wheel-running reinforcement component. Both findings attest to a reinforcement effect on operant wheel running; however, these data make an additional point that is relevant to the current study.

Removal of 15% sucrose reinforcement only reduced operant wheel running by 24% which means that in the absence of any extrinsic reinforcement, wheel running occurred at 76% of the level that it occurs when there is reinforcement. In comparison, removal of 15% sucrose decreased operant lever pressing by 90% which means that in the absence of an extrinsic reinforcement, lever pressing only occurred at 10% of the level that it occurs at when there is reinforcement. This raises two questions: Why does lever pressing occur at such a low level when there is no reinforcement, but wheel running occurs at a much higher level, and why does removal of sucrose as reinforcement produce a much larger percent decrease in lever pressing than in wheel

running? According to Belke and Pierce (2015), a fundamental difference between lever pressing and wheel running is that wheel running generates an automatic reinforcement effect, while lever pressing does not. Automatic reinforcement is “reinforcement emanating from engaging in the operant behaviour itself, not from the programmed experimental contingencies” (Belke & Pierce, 2015, p. 2). Running in a wheel generates its own reinforcement effect. Note that Iso (1996), in considering why rats ran as much in extinction as they did when food was delivered contingent upon wheel running, alluded to reinforcing stimuli other than food that may be maintaining running, which would be consistent with an automatic reinforcement effect.

Without any programmed reinforcement, wheel running will occur at a higher rate because it generates this automatic reinforcement effect. By contrast, lever pressing, which lacks this effect, occurs at a very low rate in the absence of a programmed reinforcement. Furthermore, this automatic reinforcement effect of wheel running also limits the strengthening effect of an extrinsic reinforcement such as sucrose. Specifically, the degree to which sucrose can increase wheel running between the moderate rate it occurs at due to the automatic reinforcement effect and the maximal possible wheel-running rate is less than the degree to which sucrose can increase lever pressing which lacks an automatic reinforcement effect and occurs at a very low level in the absence of extrinsic reinforcement. This is the basis for the limited control that sucrose reinforcement has over wheel running (Belke et al., 2015). The relevance of automatic reinforcement for the current study is that the effect of sucrose on wheel running on a fixed ratio schedule will be limited by this effect.

Belke et al. (2017) varied the concentration of sucrose (0%, 2.5%, 5%, 10%, and 15%) to study the reinforcing effect on operant wheel running in food-deprived and non-deprived rats. Eleven female rats were randomly assigned into two groups. One group was started at the highest concentration and then were exposed to progressively lower concentrations while the other group started at the lowest concentration and received progressively higher concentrations. The schedule of reinforcement was a FR 30 revolution schedule. The results showed that wheel-running rates collapsed across both feeding conditions increased as sucrose concentration increased. For the 0%, 2.5%, 5%, 10%, and 15% concentrations, mean rates were 30.54, 33.81, 35.30, 38.17, and 37.74 revolutions/min, respectively. When the wheel-running rates were assessed within each feeding condition, the analyses showed that when food deprived, wheel-running rates at all concentrations were significantly higher than those for 0% (water). By contrast, under ad-lib feeding, only wheel running rates generated by the 10% and 15% concentrations were significantly different than 0%. Sucrose reinforced operant wheel running with the magnitude of the reinforcement effect increasing with concentration; however, at the highest concentration the increase in wheel-running rate was modest (i.e., 7.20 revolutions/min higher than 0%). As previously stated, the magnitude of the reinforcing effect by sucrose on operant wheel running is limited by the higher operant level of wheel running that occurs without any programmed extrinsic reinforcement due to the reinforcement effect generated by running itself.

With respect to the reinforcement effects of sucrose on operant wheel running documented in the previous studies (Belke & Pierce, 2014; 2015; Belke et al., 2015; Belke et al., 2017) it is important to note that determination of the effect was based on

aggregated data. That is, the wheel-running rate for each rat for each condition (i.e., water, sucrose) was based on the total revolutions across all reinforcements in a session divided by the time taken to complete those revolutions. With these kind of data, one can determine that the wheel-running rate is higher when running is reinforced by sucrose, but one cannot tell where within the running taking place for each sucrose reinforcement the increase in running is occurring. This question of where within the reinforcement the increase in wheel running is occurring has become important because of a recent finding by Belke et al. (2021).

Belke et al. (2021) investigated the effect of different sucrose concentrations on operant wheel running on a FI 180-s schedule. Sucrose concentration was manipulated across concentrations of 0%, 5%, 15%, and 25%. Unlike the study by Belke et al. (2017) which also manipulated sucrose concentration, the pattern of operant wheel running in successive 5-s intervals within the FI 180-s schedule was measured. As with the previous studies, aggregated data showed evidence of a reinforcement effect with wheel-running rates significantly higher at 25% sucrose relative to 0%; however, the record of running within the reinforcement interval showed that wheel running systematically increased at the beginning of the interval following the occurrence of sucrose reinforcement rather than at the end of the interval just prior to sucrose reinforcement. As stated by Shahan (2017), according to the traditional response strength hypothesis of reinforcement as formulated by Skinner (1948), reinforcement strengthens the behaviour that precedes it, particularly when the occurrence of reinforcement is contingent upon that behaviour. In Belke et al. (2021), the opposite occurred. Sucrose reinforcement increased the behaviour that followed it – a result inconsistent with the traditional

concept of reinforcement. One implication of this finding is that it questions whether prior demonstrations of a reinforcement effect of sucrose on operant wheel running occurred due to increased running prior to sucrose reinforcement or following sucrose reinforcement. That brings us to the current study.

The current study aimed to determine when this effect was occurring by looking at the time taken to complete successive sets of 5 revolutions on each rat's way up to 40 revolutions when water was delivered as the outcome (no reinforcement condition) and when sucrose was delivered as outcome (reinforcement condition). By measuring the rate of running within the FR 40 schedule, I hope to determine if the increase in running that occurs when sucrose is presented is consistent with that expected based on the traditional concept of reinforcement, or the novel results found by Belke et al. (2021).

## **Method**

### **Subjects**

The experiment was conducted using eight female Long Evans rats obtained from Charles River Laboratories in Saint Constant, Quebec. Only seven completed the study. One rat was removed after falling ill unexpectedly and being subsequently euthanized. The rats were 70 days old when they began training 19 days after arriving at the lab and had no prior experience with a running wheel. They were approximately 105 days old when they started the first experimental condition (FR 40 with water). Rats were housed individually in polycarbonate cages (48.3 cm x 26.7 cm x 20.3 cm) with heat-treated beta chips and paper towel for bedding. The holding room was on a 12-hr light/dark cycle (lights on at 0730 AM) with temperature held at 20° C and relative humidity between 30% and 50%. Rats were fed Prolab R-M-H 3000 lab chow and they

were each given just enough food to hold a body weight of 260 +/- 10 g (approximately 87% of typical adult ad-lib body weight). Distilled water was freely available in the home cages throughout the study. This study complied with the guidelines of the Canadian Council on Animal Care under a protocol approved by the Mount Allison Animal Care Committee.

### **Apparatus**

The apparatus consisted of a set of four wheels. Specifically, three Lafayette wheels that were 11.5 cm wide and had metal mesh interiors with 7 mm x 7 mm openings, and one Wahmann wheel that was 11 cm wide and had a metal mesh interior with 5 mm x 5 mm openings. All wheels were 35.5 cm in diameter, and each connected mechanically to a computer. The wheels were housed in separate wall cubicles (60 cm x 50 cm x 48 cm), and each cubicle had a panel that fitted over them to block outside light. The cubicles also had two fans each for ventilation and to block extraneous noise. They each had solenoid-operated brakes with rubber-tipped shafts that would connect with their outer rims to stop them from rotating. The wheels each had a 24 V DC light attached to it 17.5 cm above its base on each side to illuminate the interior of the wheel. Revolutions were recorded by a microswitch that was attached to each wheel frame.

Each wheel had an aluminum panel (170 mm high x 170 mm wide x 2 mm thick) that had a place for a liquid receptacle (55 mm x 32 mm x 37 mm), a place for a retractable lever, and had two yellow LED stimulus lights. The liquid receptacle was located 29 mm to the left of the retractable lever, however, neither the lever nor the lights were used in the current study. The base of the receptacle opening was 75 mm above the base of the panel and had a circular depression (16 mm in diameter) in the

middle of the floor. The panels were attached to the wheel frames' openings (70 mm × 90 mm) with Velcro strips. Cylindrical dispensers that were 37 mm in diameter and 40 mm long were used to deliver the sucrose into the liquid receptacle. They had solenoid valves that were controlled by the computer so that when the wheel brakes came on, the valves opened, and the rats could take a drink. A metal clamp held the dispensers in place. Data was recorded using a Borland Turbo Pascal 4.0 program. The same program controlled the experiment. It was run on PC computers that were interfaced to the wheels through their parallel ports.

### **Procedure**

Training consisted of 17 sessions of 30 min access to a free turning wheel. This was done to habituate the rats to wheel running and allow the behaviour to stabilize. Sessions were conducted daily at 0810 AM. Following completion of those initial free wheel running sessions, the rats were started on a FR 40 reinforcement schedule where 0.1 ml of water was delivered as the outcome. When 40 revolutions were completed, the brake would be engaged, the lights at the side of the wheel would be illuminated, and 0.1 ml of water would be dispensed into the liquid receptacle. After 3.5 s to allow for possible consumption of the water, the lights at the side of the wheel would be extinguished and the brake released. This signalled the onset of the next FR 40 revolution requirement. Following the completion of a session, the liquid receptacle and the area on the base of the running wheel were checked for any unconsumed liquid. Sessions ended when 20 outcomes (800 revolutions) had been dispensed. The delivery of water as an outcome was in effect for 25 sessions. Once the sessions with water as the outcome were complete, a new set of sessions began where the outcome was changed to

0.1 ml of 25% sucrose solution. All other aspects of the operation of the schedule remained the same. Sessions with 25% sucrose as the outcome remained in effect for 25 sessions before returning to water (0% sucrose) as the outcome for a final 25 sessions.

### ***Dependent Measures***

In each session, the number of revolutions for each reinforcement was recorded, as well as the number of revolutions over the entire session. The time taken to complete the revolutions for each reinforcement and the time taken cumulatively over all reinforcements in a session was also recorded. In addition to that, the post-reinforcement pause for each reinforcement as well as the cumulative post-reinforcement pause time over all reinforcements in a session was recorded. And lastly, the number of reinforcements completed in a session was recorded.

Within each reinforcement within a session, the time taken in seconds to complete each set of successive 5 revolutions was also being recorded. In other words, the time taken to complete revolutions 1-5, 6-10, 11-15, 16-20, 21-25, 26-30, 31-35, and 36-40 revolutions on each occurrence of an FR 40 revolution requirement was recorded. Comparisons of systematic changes in these time intervals between conditions with water and sucrose as outcomes should enable us to discern when within the completion of 40 revolutions for an outcome, sucrose is affecting wheel running.

### ***Calculated Values***

Local wheel-running rate was calculated by dividing an accumulation over 20 reinforcements per session of the number of revolutions for each reinforcement, by an accumulation of the time taken to receive reinforcement and expressed the result as revolutions/min. We calculated mean post-reinforcement pause (PRP) expressed in

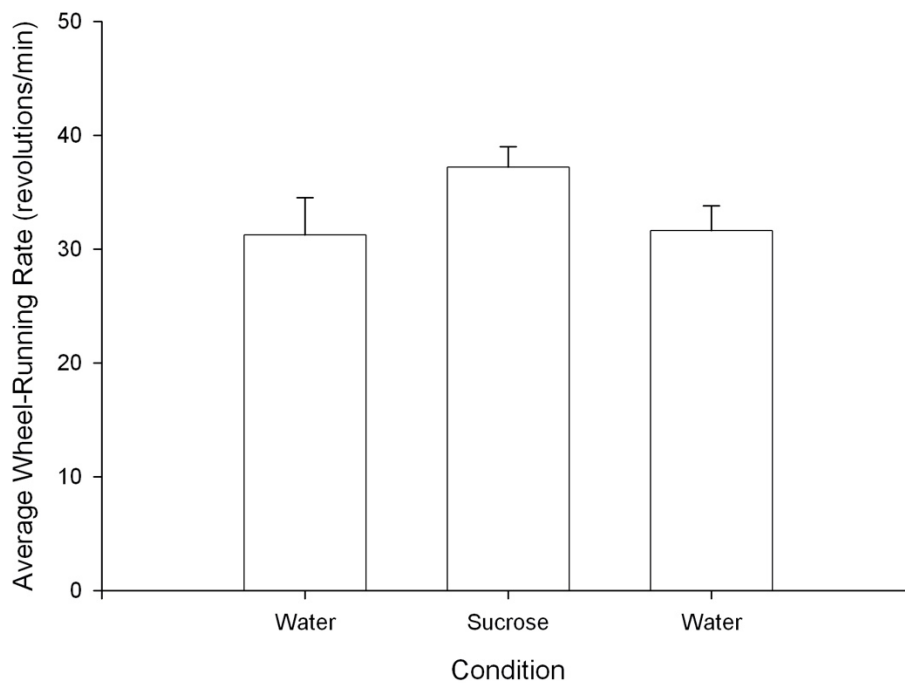
seconds by dividing the cumulative PRP over 20 reinforcements by the number of reinforcements.

## Results

Figure 1 shows operant wheel-running rates (revolutions/min) averaged across all subjects for the first water, sucrose, and second water conditions. Operant wheel-running rates across these conditions for individual rats are shown in Table 1 (see Appendix A).

### Figure 1

*Average wheel-running rates across all subjects for Water 1, Sucrose, and Water 2 conditions*

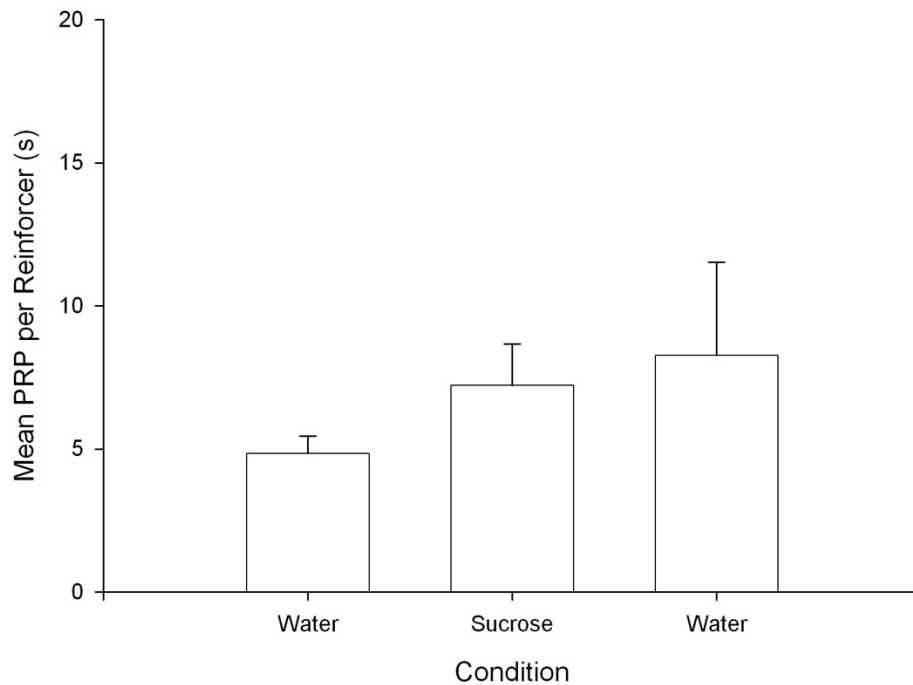


*Note.* Means and standard errors are represented.

Inspection of this figure shows that the mean aggregate or session level wheel-running rate for sucrose was higher than for the two water conditions. The water conditions appear similar, suggesting that they could be collapsed for comparison to the sucrose condition. Paired t-tests confirmed this possibility. The first water condition did not differ significantly from the second;  $t(6) = -0.313, p = .765, d = 0.05$ , and this justified the collapse. Mean wheel-running rate for sucrose was higher than the mean of the combined water condition;  $t(6) = -3.91, p < .01, d = 0.94$ .

### Figure 2

*Average PRPs across all subjects for Water 1, Sucrose, and Water 2 conditions*



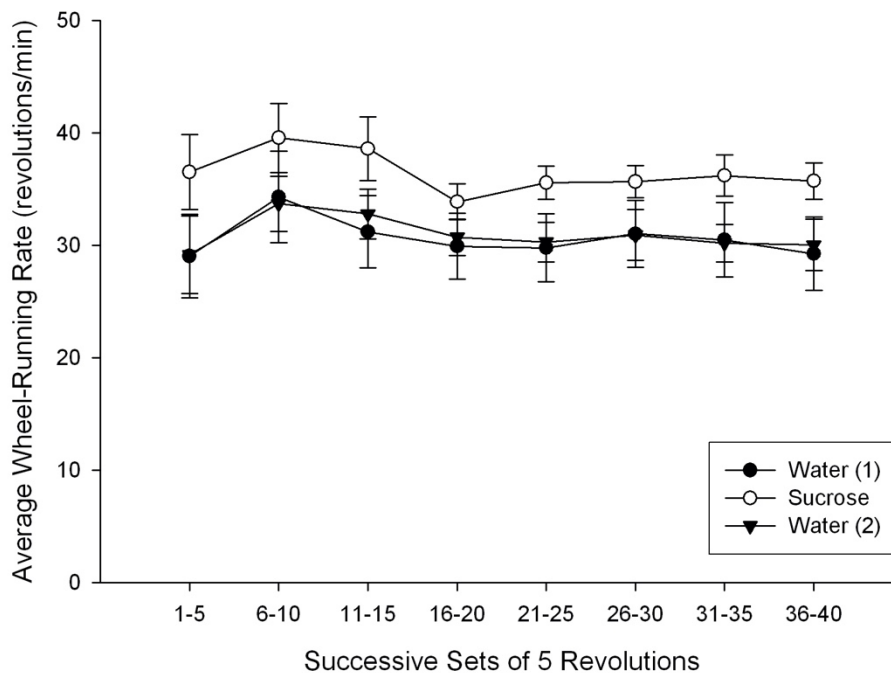
*Note.* Means and standard errors are represented.

Figure 2 shows post-reinforcement pauses (s) averaged across all subjects for the three conditions. PRPs across the conditions for individual rats are shown in Table 2 (see Appendix B). This figure shows that the mean session level PRP appeared to increase across the three conditions. This pattern occurred because the mean PRP for the second water condition did not decline back to the level of the first water condition. This occurred because the mean PRP for rat NA 1 increased from 4.51 s in the first water condition to 27.36 s in the second water condition (see Table 2). With the data from NA 1 removed, the mean PRPs for the three conditions were 4.89s, 5.87 s, and 5.08 s. For the reduced data set, the water conditions were not significantly different;  $t(5) = -0.88$ ,  $p = .417$ ,  $d = 0.10$ , and the sucrose condition did not differ from the combined water condition;  $t(5) = -1.43$ ,  $p = .213$ ,  $d = 0.52$ .

Figure 3 shows operant wheel-running rates (revolutions/min) within each 5-revolution bin averaged across all subjects for the three conditions. Operant wheel-running rates within the bins across these conditions for individual rats are shown in Table 3 (see Appendix C). Inspection of this figure shows that wheel-running rates with sucrose delivered as a consequence were increased relative to those observed when water was delivered. In terms of a pattern over the sets of 5 revolutions. Wheel-running rates in the water conditions increased from the first to the second set of 5 revolutions, then decreased and levelled off over the remainder of the sets of 5 revolutions. For the sucrose condition, wheel-running rates showed a similar pattern with the exception of a small dip at the 16-20 revolutions, where the difference between sucrose and water wheel-running rates appears to diminish, then subsequently increase.

**Figure 3**

*Average wheel-running rates for Water 1, Sucrose, and Water 2 shown for each 5-revolution bin*



*Note.* Means and standard errors are represented.

A two-way repeated measures ANOVA for the two water conditions revealed a non-significant main effect for condition (first, second);  $F(1, 6) = 0.084, p = .781, \eta_p^2 = 0.014$ . However, there was a significant main effect for the sets of 5 revolutions;  $F(7, 42) = 4.78, p < .001, \eta_p^2 = 0.444$ . The interaction between the sets of five revolutions and the water conditions was not significant  $F(7, 42) = 0.403, p = .895, \eta_p^2 = 0.063$ . The lack of a significant effect for condition as well as the interaction justified collapsing the water conditions. These means are shown in Figure 3.

The mean wheel-running rates for the combined water and sucrose conditions were 30.80 and 36.46 revolutions/min respectively. For the comparison of the combined

water conditions with sucrose, a two-way repeated measures ANOVA revealed a significant main effect of type of outcome (water, sucrose);  $F(1, 6) = 14.51, p = .009, \eta_p^2 = 0.707$ .

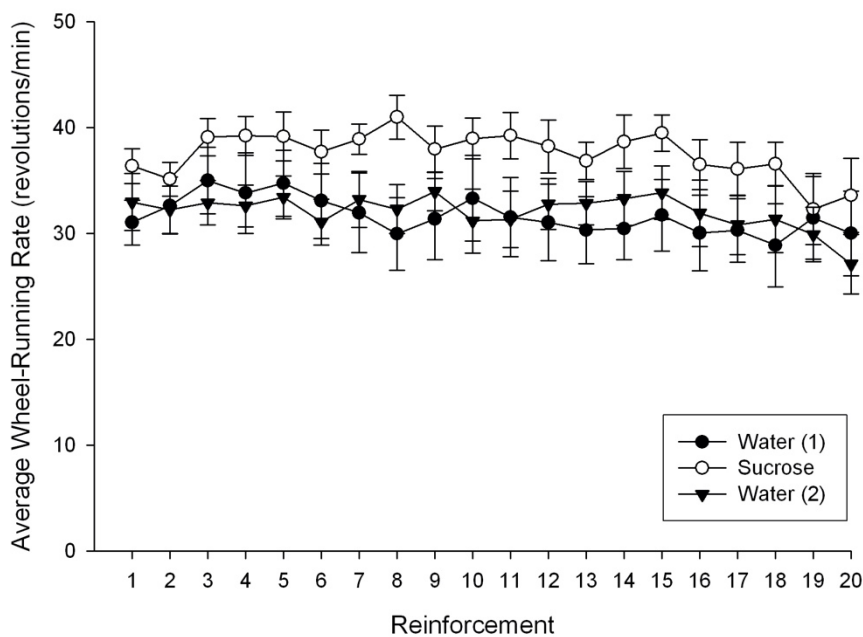
There was also a significant main effect for the sets of five revolutions;  $F(7, 42) = 3.42, p = .006, \eta_p^2 = 0.363$ , the means of which, from the first set to the last, were 32.81, 36.77, 35.29, 32.09, 32.80, 33.31, 33.28, and 32.68 revolutions/min. Tukey HSD comparisons showed that wheel-running rates for revolutions 1-5 were significantly lower than those for revolutions 6-10 ( $p = .04$ ) regardless of reinforcement. Furthermore, wheel-running rates for revolutions 6-10 were significantly higher than those for revolutions 16-20, 21-25, and 36-40 (all  $ps < .05$ ). Despite this, there was no significant interaction for type of outcome and the sets of 5 revolutions;  $F(7, 42) = 0.769, p = .617, \eta_p^2 = 0.114$ , as can be seen in Figure 3.

Figure 4 shows operant wheel-running rates (revolutions/min) for each reinforcement averaged across all subjects for the three conditions. Operant wheel-running rates across these conditions per reinforcement for individual rats are shown in Table 4 (see Appendix D). This figure shows that operant wheel-running rates for each reinforcement during the sucrose condition were higher than in both water conditions throughout most of the session.

The mean rates of the first water, sucrose, and second water conditions were 31.63, 37.55, and 32.05 revolutions/min respectively. A two-way repeated measures

**Figure 4**

*Average wheel-running rates for Water 1, Sucrose, and Water 2 shown for each reinforcement*



*Note.* Means and standard errors are represented.

ANOVA revealed a significant main effect for condition (water, sucrose, water);  $F(2, 12) = 10.46, p = .002, \eta_p^2 = 0.64$ . Tukey HSD comparisons showed that average wheel-running rates for Water 1 and Water 2 were significantly lower than for sucrose;  $p = .004$  and  $.007$ , respectively, but no difference between the water conditions. There was a significant main effect for reinforcement,  $F(19, 114) = 2.13, p = .008, \eta_p^2 = 0.26$ , where mean rates were 33.45, 33.33, 35.66, 35.22, 35.77, 33.95, 34.69, 34.42, 34.43, 34.48, 34.04, 34.01, 33.33, 34.13, 35.02, 32.82, 32.39, 32.25, 31.22, and 30.24 revolutions/min. Tukey HSD comparisons showed that wheel-running rates at the third and fifth reinforcements were significantly higher than at the twentieth reinforcement;  $p = .019, .014$ .

The interaction between the three conditions and reinforcement was also significant,  $F(38, 228) = 1.66, p = .013, \eta_p^2 = 0.220$ . Tukey HSD comparisons showed no significant differences between the mean wheel-running rates across reinforcements for Water 1, however, there were differences between the mean rates for Water 2 and the mean rates in the sucrose condition depending on the reinforcement. For Water 2, the mean wheel-running rates at the fifth, ninth, and fifteenth reinforcements were significantly higher than the mean rate at the twentieth reinforcement;  $p = .04, .01, .013$ . For the sucrose condition, mean wheel-running rate for the nineteenth reinforcement was significantly lower than mean rates at the third ( $p = .001$ ), fourth ( $p = .008$ ), fifth ( $p = .01$ ), seventh ( $p = .019$ ), eighth ( $p < .001$ ), tenth ( $p = .016$ ), eleventh ( $p = .007$ ), fourteenth ( $p = .036$ ), and fifteenth ( $p = .004$ ) reinforcements. As well as this, the mean rate at the twentieth reinforcement was significantly lower than the mean rate at the eighth ( $p = .002$ ) reinforcement. These means are depicted in Figure 4.

### Discussion

Similar to previous studies (Belke & Pierce, 2014; 2015; Belke et al., 2015; Belke et al., 2017; Belke et al., 2021), the delivery of sucrose as a contingent outcome for operant wheel running increased wheel-running rates at the session level relative to water as an outcome. Unlike previous studies, this study showed that the increased aggregate wheel-running rates with sucrose occurred due to sucrose increasing operant wheel running over the entire ratio schedule. This outcome contradicts a recent finding by Belke et al. (2021) that showed a schedule-induced increase in wheel running at the beginning of a fixed interval schedule as well as an unsystematic increase in wheel running rates over the remainder of the schedule interval. In the current study, there was

no evidence for a schedule-induced increase in running at the beginning of the FR schedule. The reason for this difference in findings remains to be investigated. Finally, there was no evidence of any systematic within-session changes in operant wheel-running rates over the reinforcement within a session with either water or sucrose as outcomes.

Based on a review of the literature, it was predicted that when sucrose was delivered contingent upon wheel running, wheel-running rate would increase significantly at the beginning, or the end of the FR-40 schedule. Neither of these effects occurred. The prediction that sucrose reinforcement would increase operant running at the end of the schedule was based upon the traditional concept of reinforcement (Shahan, 2017; Skinner, 1948). This concept suggests that a reinforcing consequence should produce the greatest strengthening effect on responding closest in time to the reinforcement, and as one goes further back in time prior to the reinforcement, the strengthening effect would diminish. That is, the highest rate of responding should occur just prior to the reinforcement. This pattern can be seen in the break-and-run pattern known to develop on FR schedules (de Carvalho et al., 2018; Dews, 1978; Rider, 1977, 1980; Taylor et al., 2010), as well as in the fixed interval scallop that occurs on FI schedules (Baron & Leinenweber, 1994; Berry et al., 2012; Belke, Pierce & Welsh, 2018; Cole, 2001; Dews, 1978; Schneider, 1969) with operant behaviors such as lever pressing, or key pecking in pigeons. After a reinforcement has been delivered, there is a period of little to no responding which is followed by a high rate of responding on FR schedules up to the response that produces reinforcement. After reinforcement on an FI schedule, there is also a period of little to no responding that lasts approximately half of

the reinforcement interval followed by an acceleration of responding up to the moment in time when a response will produce reinforcement. These commonly observed patterns conform to this definition of a traditional reinforcement effect and can be observed with operant behaviors that have no automatic reinforcement effect.

By contrast, operant wheel running, a behavior that generates its own automatic reinforcement effect, produces different patterns on these schedules. Since this is the first assessment of the pattern of operant wheel running on a FR schedule, there are no prior studies for comparison. However, there have been prior studies with patterns on FI schedules. Operant wheel running does not produce the same pattern on a FI schedule that lever pressing does (Belke et al., 2018). Instead of a scallop, operant running rises quickly at the beginning of the fixed interval up to a peak around 9-12 s, then declines slightly and plateaus over the remainder of the interval. Belke et al. (2018) found this same pattern for operant wheel running on FI 15-s, 30-s, and 60-s schedules. This pattern does not show a long pause following reinforcement followed by acceleration in responding up to the moment of reinforcement. According to Belke et al. (2018) the reason is that running generates its own reinforcement effect so that the effect of the sucrose reinforcement must interact with this running generated reinforcement effect to produce its reinforcement effect. Unfortunately, Belke et al. (2018) did not compare operant running with and without sucrose reinforcement as was the case in the current study to be able to directly observe the effect of the sucrose reinforcement.

The effect observed in the current study of an increased wheel-running rate over the entire 40 revolutions likely reflects this interaction of sucrose reinforcement with pattern of responding generated by the automatic reinforcement generated by wheel

running. As such, the reinforcement effect of sucrose extended over all of the behavior rather than showing a differential strengthening effect near the end of the 40 revolutions. Support for this speculation comes from McClelland's (2022) thesis project recently carried out in this lab. McClelland (2022) investigated the effect of water and sucrose as outcomes for operant wheel running on a FI 60-s schedule. Revolutions were recorded in successive 5-s segments of the 60 s reinforcement interval over the 20 outcomes (water, sucrose) delivered in the study. With water delivered as the outcome, running rose from an intermediate level and then levelled off over the remainder of the interval. With sucrose as the outcome, running rose rapidly from a lower level as rats took time to consume the sucrose up to a higher level then leveled off over the remainder of the interval. The level of revolutions with sucrose being presented was higher than that for water over the final 45-s of the 60-s interval. This consistent increase in revolutions over the final 45-s of the interval appears similar to the consistent increase observed over the entire FR 40 in the current study. The major difference was that the increase was observed over the entire FR 40, but only over the final 45-s on the FI 60-s schedule. The reason for this difference may be due to the systematically longer PRP observed at the beginning of the FI schedule when sucrose was present. As stated, previously, this occurred because rats took time to consume the sucrose, but not the water. In the current study, PRPs were not systematically longer when sucrose was present in comparison to water.

Belke et al. (2021) observed a similar, although less consistent, effect of sucrose reinforcement on operant wheel running on a FI 180-s schedule. Averaged across all rats, wheel revolutions for the 15% and 25% sucrose conditions were higher on average

over most of the 180-s interval from 35-40 s onward. The increase was not sufficiently consistent across rats to produce a significant effect of sucrose concentration over this part of the FI interval, but it does appear similar to the effect observed in the unpublished bachelor's thesis project as well as that observed in the current study. Taken together, these observations suggest that the effect of sucrose reinforcement on the pattern of responding generated by an automatically reinforced operant behavior can differ from that observed with more conventional operant behaviors.

An alternative explanation for the observed reinforcement effect that has yet to be considered comes from Skinner and Morse (1958). They made the distinction between discrete and continuous behavior. As they defined it, a discrete behavior is a behavior with an identifiable beginning and end that can be counted as a unit, like a lever press. A continuous behavior is one that cannot necessarily be counted as a unit and has a less clear beginning and end, like running. They raise the question of how wheel-running rate can be counted as units and whether the measured units are meaningful for the rat. The measure of a wheel revolution is an arbitrary unit used to characterize this behavior; however, for the rat, running occurs in bouts, and these bouts may constitute the functional unit of this behavior. As stated above, the potential contribution of this aspect of wheel running has yet to be investigated.

While there was a reinforcement effect for sucrose, there was no evidence for a schedule-induced increase in wheel running due to periodic presentation of sucrose. An increase at the beginning of the FR 40 would be consistent with a schedule-induced behavior, however, this did not occur. Nor was there evidence for a schedule-induced increase in wheel-running at the beginning of the FI 60-s schedule of operant wheel

running in McClelland's (2022) project. This contrasts with the findings by Belke et al. (2021) which clearly showed a schedule-induced increase in operant wheel running during the first 35-s of the 180-s reinforcement interval. The absence of evidence of schedule-induced running in these two studies begs the question of what differed between the current study and that by Belke et al. (2021). One possibility, although it would require further investigation to validate, is the duration required to complete the schedule requirement.

In the current study, the average time, including PRP times, to complete 40 revolutions during the sucrose condition was 72.7 s ( $SE = 3.8$  s) with a range of 58.9 s to 86.7 s. In McClelland's (2022) project, the FI schedule interval was 60-s. Both of these studies showed evidence for a consistent increase in operant wheel running overall, if not for most of the schedule, but no evidence of a schedule-induced increase in running. By comparison, the much longer 180-s schedule interval for sucrose presentation in Belke et al. (2021), produced a schedule-induced increase in responding at the beginning and an inconsistent increase in running over the remainder of the interval. To test the hypothesis that the duration required to complete the schedule requirement makes a difference, future research should compare the effect of sucrose reinforcement on operant wheel running on shorter and longer schedules within the same rats. For example, operant running on a FI 60-s compared with operant running on a FI 180-s schedule in the same rats. Or, as an extension of the current study, compare operant wheel running on a FR 40 schedule with that on a FR 120 schedule

Operant wheel-running rates did not show any systematic changes within a session over reinforcements. The second experiment in Belke et al. (2021) also failed to

show any systematic within-session changes in operant wheel-running rates over reinforcements when sucrose concentration was manipulated as reinforcement for operant running on a FI 180-s schedule. The significance of these observations is that they differ from those previously observed by McSweeney and colleagues with key pecking and lever pressing as operant behaviors (McSweeney et al., 1995; McSweeney & Roll, 1998; McSweeney & Swindell, 1999; McSweeney & Murphy, 2000; 2009). According to McSweeney's (1995) sensitization-habituation theory, changes in behavior within a session can be observed even when the schedule of reinforcement is held constant due to repeated presentation of a reinforcing stimulus over a long period of time. Habituation can cause an operant response (i.e., lever pressing) to decrease within a session over reinforcements because the rats become less sensitive to the sensory properties of reinforcing stimuli. Sensitization has the opposite effect. Rats become more sensitive to the sensory properties of the stimuli and their responding increases over reinforcements within a session. Neither process appeared to occur with operant wheel running in the current study or the prior study by Belke et al. (2021). There was no evidence of an increase or a decrease across reinforcements. These within session patterns of responding may have occurred if the rats had been lever pressing instead of running for sucrose reinforcement. This suggests that the absence of these within-session patterns of responding is likely due to a difference between wheel running and other operant behaviors such as the automatic reinforcement effect generated by wheel running (Pierce et al., 2018). Future research into this topic should begin by comparing within-session patterns generated within the same rats with wheel running and lever pressing as operants producing the same reinforcement.

One issue that could have arisen, but did not, that would have affected the results of the current study was if the rats completed the schedule requirement but failed to drink the sucrose solution that was delivered. A well-documented reason for this is that wheel running can induce nausea. Nakajima and Katayama (2014) demonstrated this phenomenon by showing that rats would consume more of a non-food item like kaolin clay after running. Such behavior, called pica, has also been shown to occur after nausea-inducing treatments like irradiation. Therefore, if their rats exhibited this behavior after engaging in wheel running, that would effectively show that the running made them nauseous. In the current study, the liquid receptacle and the area around the base of the running wheel were checked for fluid after each session. If the rats had not consumed the sucrose, then it would have leaked out of the receptacle and onto the base of the wheel. Paper towel under the wheel would have soaked it up or it would have pooled in the area under the receptacle. This check, which was manually performed at the end of every session, revealed that the rats were consuming the sucrose, but not the water.

This was likely due to the rats having been exposed to running in wheels before the experimental sessions began. Nakajima et al. (2006) showed that pre-exposure to wheel running can stop taste aversion to a flavour consumed prior to running due to nausea from developing. In the current study, there were 17 pre-exposure sessions and 25 water sessions before the experimental sessions with sucrose as the outcome even took place. Based on the data from Nakajima et al. (2006), this should have been more than enough pre-exposure to wheel running to habituate the rats to any nausea induced by initial exposure to a running wheel. It is important to mention this issue as it would

have been a serious confound in the current study. The manual checks, however, showed that in all cases, the rats were consuming the sucrose solution that was delivered and as such, the increased running that occurred with sucrose as an outcome was due to a reinforcement effect on, or a schedule-induced increase in operant wheel running.

Overall, the data collected from the current study appears to show a general reinforcement effect rather than the schedule-induced effect that was hypothesized to occur. The general reinforcement effect took the form of increased running over the entire ratio schedule, the pattern of which was largely determined by the automatic reinforcement effect generated by wheel running, although the continuous rather than discrete nature of wheel running does need to be considered. No schedule-induced effect on wheel running was observed and this may have been due to the time taken to complete the reinforcement schedule being too short. Therefore, further research should be conducted to determine if a schedule-induced effect would present when schedules of reinforcement are longer.

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**Appendix A****Table 1**

*Operant wheel-running rate (revolutions/min) for the Water 1, Sucrose, and Water 2 conditions for each rat*

Rat	Water (1)	Sucrose	Water (2)
NA1	22.02	34.93	26.30
NA2	19.41	29.81	24.02
NA3	38.75	42.33	38.04
NA4	27.16	36.32	27.89
NA10	36.15	34.22	32.95
NA11	32.64	39.40	33.26
NA12	42.50	43.26	38.87

**Appendix B****Table 2**

*Average PRP per reinforcer (s) for the Water 1, Sucrose, and Water 2 conditions for each rat*

Rat	Water (1)	Sucrose	Water (2)
NA1	4.51	15.28	27.36
NA2	5.84	6.17	6.72
NA3	5.52	7.00	6.02
NA4	7.46	6.34	7.68
NA10	3.81	4.67	3.28
NA11	4.37	7.58	4.09
NA12	2.33	3.48	2.66

## Appendix C

**Table 3**

*Average wheel-running rates (revolutions/min) across successive sets of five revolutions for the Water 1, Sucrose, and Water 2 conditions for each rat*

Rat	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
Water (1)								
NA1	20.13	22.31	23.82	24.66	21.28	21.45	22.98	20.32
NA2	22.14	19.65	19.06	19.65	18.81	20.00	17.61	18.98
NA3	41.53	45.61	38.82	36.55	36.71	36.91	38.51	36.96
NA4	29.85	28.93	26.74	26.06	27.08	29.60	24.82	25.22
NA10	41.78	39.65	35.49	33.07	33.21	37.39	35.04	35.30
NA11	50.92	38.14	31.70	27.40	30.66	31.99	33.48	26.72
NA12	47.75	45.79	42.79	42.08	40.69	39.82	41.06	41.24
Sucrose								
NA1	39.02	38.46	34.53	27.78	34.90	35.72	42.28	31.12
NA2	35.59	27.59	28.12	28.87	27.47	30.49	30.35	31.55
NA3	63.61	41.65	44.80	38.87	38.57	39.37	39.69	40.47
NA4	37.22	35.08	37.34	36.72	37.77	36.51	34.42	35.78
NA10	37.96	35.89	33.82	32.34	35.25	30.75	30.67	32.66
NA11	49.64	45.38	41.06	35.96	39.04	36.88	34.89	36.59
NA12	56.45	52.77	50.45	36.53	35.96	39.90	41.16	41.88
Water (2)								
NA1	29.71	27.65	29.41	27.27	26.52	25.87	23.87	22.02
NA2	22.63	25.88	23.89	24.96	23.52	22.60	25.61	23.51
NA3	52.11	41.91	37.84	34.23	35.20	38.15	35.06	35.13
NA4	26.20	28.55	30.32	28.08	27.25	27.22	28.72	27.19
NA10	32.68	34.45	34.83	30.88	31.60	34.20	33.32	32.04
NA11	43.58	36.78	31.64	32.28	31.94	31.16	30.20	31.97
NA12	48.21	40.60	41.61	37.34	35.99	37.24	34.52	38.42

## Appendix D

**Table 4**

*Average wheel-running rates (revolutions/min) for each reinforcer within a session for the Water 1, Sucrose, and Water 2 conditions for each rat*

Water(1)		Reinforcer																		
Rat	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NA1	29.6	29.2	29.0	23.3	29.8	22.4	18.8	18.1	19.8	19.7	22.8	18.1	26.1	21.1	25.8	19.3	24.1	16.6	18.4	22.1
NA2	27.0	22.1	21.1	19.3	20.8	17.4	20.0	17.5	16.5	20.0	17.5	22.2	17.4	20.0	20.4	20.3	19.4	16.9	18.8	18.0
NA3	29.2	31.2	41.2	37.5	35.1	41.8	42.1	39.0	40.9	43.8	44.8	37.9	38.7	36.0	42.0	37.8	37.1	41.4	42.6	42.9
NA4	25.7	29.3	31.9	29.0	31.9	35.0	27.9	27.8	28.8	28.5	29.5	24.6	25.8	29.0	25.5	21.4	24.4	25.2	26.1	22.4
NA10	34.0	32.9	35.4	38.9	39.8	36.6	39.0	35.7	39.1	40.5	35.4	35.9	36.7	32.5	37.4	33.0	35.3	33.9	37.8	35.1
NA11	29.3	41.6	40.7	42.3	39.3	37.0	33.4	33.0	32.2	35.3	28.4	33.7	27.1	33.0	27.8	35.8	30.5	26.6	34.3	25.3
NA12	42.1	41.8	45.4	46.2	46.2	41.0	42.2	38.3	41.9	45.0	41.9	44.6	40.1	41.2	42.8	42.3	40.9	41.3	42.0	43.9

Sucrose		Reinforcer																		
Rat	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NA1	40.5	36.1	40.3	39.3	38.5	37.5	35.3	40.9	37.3	33.6	33.7	38.4	31.5	38.5	40.6	35.0	29.4	30.2	25.5	28.1
NA2	31.1	26.1	31.8	33.0	32.8	27.2	33.7	33.3	29.4	32.5	32.1	24.7	30.6	27.3	30.7	26.2	29.6	31.3	32.3	25.2
NA3	33.0	37.2	42.8	39.4	42.7	41.7	42.0	45.9	44.6	40.7	45.5	43.8	42.8	46.7	45.7	43.2	40.9	43.4	44.7	44.4
NA4	36.1	35.7	34.8	34.8	33.5	36.9	38.5	33.7	35.3	37.6	40.2	39.5	37.5	38.4	38.2	39.1	39.3	35.6	33.9	30.4
NA10	34.2	37.9	37.9	36.8	33.5	34.8	39.1	42.2	32.9	39.5	36.6	38.7	35.6	32.9	39.7	30.6	31.3	35.2	18.3	24.6
NA11	35.6	38.3	45.5	46.1	45.7	43.2	44.7	43.0	43.4	40.5	38.6	37.2	38.1	42.9	39.8	38.8	34.6	35.9	30.3	34.5
NA12	43.7	34.1	40.4	44.8	47.1	42.1	38.8	47.5	42.6	48.0	47.7	45.0	41.6	43.6	41.4	42.3	47.1	44.0	40.8	47.8

Water(2)		Reinforcer																		
Rat	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NA1	37.1	29.3	31.8	28.2	25.8	25.3	25.9	25.5	29.1	17.4	25.6	29.6	26.1	21.1	25.8	19.3	24.1	16.6	18.4	22.1
NA2	27.0	21.2	23.1	26.6	29.3	25.4	25.3	23.8	27.6	24.5	21.0	22.8	25.7	22.0	24.9	24.7	23.7	24.8	22.0	19.0
NA3	30.5	36.0	35.2	38.4	36.7	37.8	35.8	38.6	38.7	38.7	41.0	40.3	38.6	37.5	41.1	41.7	39.5	38.2	39.4	39.9
NA4	27.7	30.4	30.8	27.8	31.3	28.5	28.0	30.7	30.1	28.9	27.0	27.7	29.3	29.3	33.2	28.2	24.7	19.3	23.2	28.3
NA10	30.0	32.8	32.3	32.1	31.5	27.0	34.7	34.0	36.7	33.7	33.5	39.2	32.9	38.4	34.0	28.9	36.5	39.2	33.2	25.4
NA11	30.9	38.4	41.3	39.0	40.5	36.6	38.6	33.1	35.9	35.5	33.8	34.8	36.8	35.8	32.5	34.2	30.4	27.7	26.4	20.2
NA12	47.2	37.3	35.4	35.7	38.7	36.6	44.0	40.1	39.3	39.3	37.1	34.7	38.7	40.8	43.5	43.7	38.5	41.1	37.2	33.3

## Appendix E

**Table 5**

*Average PRP (s) for each reinforcer within a session for the Water 1, Sucrose, and Water 2 conditions for each rat*

Water(1)		Reinforcer																		
Rat	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NA1	2.6	3.9	2.9	5.2	7.0	9.0	5.6	3.0	4.4	3.0	1.8	10.1	2.7	2.3	8.6	3.5	3.6	3.6	2.9	4.6
NA2	2.3	5.8	9.4	6.8	7.7	6.8	3.6	10.8	5.5	3.4	1.9	2.2	2.8	4.7	2.3	3.5	5.1	4.3	3.4	24.7
NA3	3.0	4.1	5.7	5.2	10.3	7.8	4.3	5.3	5.0	1.9	2.5	4.3	4.2	7.0	3.2	19.4	8.1	3.1	4.0	2.1
NA4	2.6	3.1	5.5	4.4	4.8	5.4	4.9	7.0	9.4	5.6	5.6	7.0	11.4	10.0	9.5	9.1	8.7	11.5	11.2	12.2
NA10	2.8	2.7	5.1	3.5	4.2	3.0	4.8	6.0	4.0	4.0	3.6	1.7	4.7	3.8	4.6	3.4	2.0	2.9	4.0	5.5
NA11	1.3	4.4	4.1	6.0	9.7	2.2	3.7	5.4	7.1	3.9	7.7	4.8	2.6	3.8	3.6	2.4	4.4	5.2	2.6	2.8
NA12	2.4	2.3	2.2	3.2	1.3	2.3	2.0	2.7	2.8	2.3	2.4	1.7	2.4	2.7	2.3	2.2	1.6	2.2	2.6	3.0

Sucrose		Reinforcer																		
Rat	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NA1	1.4	11.0	12.9	17.1	17.6	13.2	14.9	17.6	25.7	15.8	17.4	12.6	14.2	12.6	16.4	17.4	18.7	15.3	19.3	14.7
NA2	1.3	7.0	5.1	6.9	6.5	8.4	7.2	8.2	6.0	7.9	4.7	7.1	7.5	6.0	5.0	6.4	4.0	6.0	6.2	6.1
NA3	4.5	5.2	5.5	9.7	8.3	4.3	10.3	5.6	4.0	3.9	10.1	13.7	3.4	7.2	6.5	4.6	10.8	8.9	6.2	7.4
NA4	2.1	10.0	5.4	6.5	7.6	5.5	8.0	4.6	6.4	6.5	7.3	5.7	5.5	9.4	5.8	5.1	5.8	7.2	5.6	6.9
NA10	2.1	6.7	4.3	5.6	4.0	5.7	5.0	4.3	4.5	2.7	2.8	5.4	7.0	2.7	7.2	3.5	4.0	6.0	6.3	3.5
NA11	1.6	8.4	8.4	6.1	8.3	7.4	7.2	7.1	6.7	7.6	8.6	8.3	8.9	9.1	7.0	6.1	8.2	9.7	7.4	9.6
NA12	2.1	2.9	4.5	4.1	4.8	4.4	4.0	1.9	2.1	2.3	3.2	4.3	3.3	3.0	3.8	4.6	4.3	2.8	3.5	3.6

Water(2)		Reinforcer																		
Rat	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NA1	0.9	7.8	5.3	5.5	9.7	11.7	14.0	9.2	8.7	27.1	50.7	73.9	23.5	52.0	6.9	36.5	32.0	42.6	57.0	72.1
NA2	1.3	3.7	2.4	4.1	2.3	2.7	7.1	2.5	6.5	12.1	9.7	5.0	6.3	12.7	9.1	4.9	4.2	4.8	11.6	21.3
NA3	1.3	6.3	11.2	10.2	6.6	4.3	5.3	6.5	7.1	4.2	4.9	3.8	4.4	6.2	4.1	8.6	4.6	4.8	7.6	8.4
NA4	1.8	6.0	4.6	4.4	6.4	2.4	8.7	11.1	6.6	7.2	7.3	8.7	7.3	10.1	9.0	8.4	9.8	11.8	10.0	12.0
NA10	1.4	2.6	3.9	4.0	2.3	1.6	4.3	1.3	2.3	1.6	2.4	3.1	2.8	4.1	1.5	4.7	3.3	8.0	6.5	4.1
NA11	2.2	4.2	3.1	3.7	2.7	2.4	2.8	2.1	4.3	3.7	3.4	3.6	5.3	4.2	5.8	2.2	4.2	4.9	11.0	6.1
NA12	1.5	1.5	2.4	2.5	2.3	1.8	3.4	3.4	2.1	2.6	4.0	4.8	3.1	1.9	2.4	2.6	2.9	2.5	2.7	2.8