Time-of-day affects the amount rats run during daily sessions in activity wheels

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Abstract

When rats are given daily sessions of access to activity wheels, the amount that they run can increase over sessions. In addition to the suggestion that this could indicate the development of an addiction, there are alternative explanations. The present study tested whether running at a fixed time of day (ToD) might allow stronger entrainment of circadian rhythms than running at varied ToDs. In two experiments, Fixed groups of male rats were given 90-min wheel sessions at a fixed ToD during their dark period, while such sessions for Varied groups were given at times that varied over days between early in or in the middle of the dark period. In addition, each experiment also contained inactive controls in order to assess running-induced changes in body weight. Daily wheel sessions were given for 12 days in Experiment 1 and for 18 days in Experiment 2 to younger rats. In Experiment 1 the Fixed groups ran more each day, whereas little increase was found in the Varied groups. In Experiment 2 this difference was found only for rats in the Fixed condition whose sessions were held in the middle of the dark period. Independent of condition, rats ran more in the middle than early in the dark period. As previously reported, the rats given wheel access consumed less food and gained less weight than inactive rats. In conclusion, the results provided support for the proposal that wheel sessions at a fixed ToD entrain circadian rhythms and thus facilitate increases in running.

Keywords Wheel running · Time-of-day · Circadian entrainment · Exercise · Rats

Introduction

As with many other species, when given access to activity wheels, rats tend to run in the absence of any external incentive or reinforcement and sometimes cover the equivalent of a considerable distance in a short period of time (Sherwin, 1998). One reason why wheel running in rats is interesting is that it provides a potential animal model of human exercise (Eikelboom, 1999). It has been generally found that rats tend to run more as their experience with the wheels increases until they reach an asymptote (e.g., Tokuyama, Saito, & Okuda, 1982).

Some researchers have suggested that increased running by rats reflects the development of an addiction (e.g., Berczik, Szabo, Griffiths, et al., 2012; Kanarek, D'Anci, Jurdak, & Mathes, 2009). Alternatively, increased running may reflect increased fitness (Afonso & Eikelboom, 2003; Sherwin, 1998). However, the fitness theory cannot provide a complete

explanation for this effect. First, it cannot explain the lack of increase in wheel turns in rats with 2-h daily wheel access during the day cycle. Second, it does not explain why animals under food restriction increase their wheel running more rapidly than those that are not (Lattanzio & Eikelboom, 2003).

As documented in the large number of studies that have followed Richter (1922), rats normally exhibit circadian rhythms whereby they normally sleep during the daylight hours and are most active during the dark hours (Afonso & Eikelboom, 2003; Bolles & Lorge, 1962; Mistlberger, 1994; Stewart, Rosenwasser, & Adler, 1984). When given 24-h access to food and to an activity wheel, rats run mostly during the dark cycle (e.g., Eikelboom & Mills, 1988; Mistlberger, 1994; Morse, Russell, Hunt, et al., 1995). When given such access for only a limited time each day, increased running can occur when as little as 1 h of wheel access is given during the dark period, whereas providing 2 h of wheel access during the light period failed to produce the same effect (Eikelboom & Lattanzio, 2003). Although rats' circadian rhythms of activity are normally driven by light cycles, they can be changed by imposing limited access at fixed times to both food and an activity wheel (e.g., Mistlberger, 1991; Mrosovsky, 1996).

The proposal tested in the present study is that, first, such entrainment is more likely to occur when access to a wheel is

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provided at a fixed time of day (ToD) than at varied times, and, second, that such entrainment leads to increased running. The closest any study has come to testing such a proposal appears to be one using mice in which access to activity wheels was given in the middle of the light period, at the onset of the dark period, or in the middle of the dark period. Increased running was found only in the two groups given 3-h access to activity wheels in the dark period; however, increased proliferation of hippocampal neurons, the main focus of the study, was found only the group given 3-h access in the middle of the dark period. It may be noted that no mice in this study were given access to the wheels at varied times (Holmes, Galea, Mistlberger & Kempermann, 2004).

Experiment 1

The aim of Experiment 1 was to test the prediction that rats given 90-min access to an activity wheel at varied ToD (Varied condition) would increase the amount that they ran more slowly than rats given such access at the same ToD (Fixed condition). In the factorial 2×2 design of the main experiment, one factor was Schedule, that is whether the rats were run at a Fixed or Varied ToD, and the second factor was whether the first experimental session took place at the onset of the dark period (Early) or in the middle of the dark period (Mid). This generated the four main experimental groups: Fixed-Early, Fixed-Mid, Varied-Early, and Varied-Mid.

Wheel running can influence rats' body weight and food consumption. When rats with unrestricted access to food are first given access to activity wheels, both their food consumption and weight gain can decrease; food consumption usually returns to normal after a few days, but the reduction in body weight can last for a longer period (Looy and Eikelboom, 1989; Tokuyama et al., 1982). Surprisingly, both 2-h and 24-h access to wheels have been found to produce similar effects on feeding and body weight (Afonso & Eikelboom, 2003; Lattanzio & Eikelboom, 2003).

In the context of such reports, a secondary aim of the present study was to compare the impact on body weight of fixed and varied times of access to the wheels. Accordingly, additional rats were allocated to a Control condition in which they were transferred to the wheel room but were not given access to an activity wheel; these rats served as inactive controls to detect any effects of running on weight gain. Rats in this condition were allocated to two groups, Control-Early and Control-Mid, which differed only in whether the rats were transported to the wheel room at the start of the dark period or 6 h later.

Method

Subjects The 32 male Sprague Dawley rats were 14 weeks old at the start of the experiment. They had no prior experience of

activity wheels but had previously served in a flavor preference experiment in which they were exposed to a sucrose solution and a vanilla flavor. The rats were group-housed, four to a cage, throughout this and the previous experiment in a colony room (vivarium) that was maintained on a reversed 12:12 light cycle, with lights out at 1000 h. *Ad lib* access to chow (Specialty Feeds®, 3.4 kcal/g, Glen Forrest, WA, Australia) and water was maintained throughout the experiment, except during wheel-running sessions (see below).

In this first experiment only 11 activity wheels were available. Six rats were allocated to each of the two Fixed groups and five were allocated to each of the two Varied groups. Half of the remaining ten rats were allocated to the Control-Early group and the other half to the Control-Mid group. These allocations were based on minimizing weight differences without transferring rats to different cages. The result was that in six of the group cages the rats were all in the same condition, while rats were from different conditions for the remaining two cages.

Apparatus Each of 12 activity wheels, with a diameter of 36 cm and width of 10 cm, could be entered from a side chamber, $20 \times 30 \times 20$ cm (Med Associates “Activity wheel with chamber” ENV-042A W/ENV-042OE). Each complete wheel turn equaled a distance of 1.13 m. The 10×5 cm doorway between the wheel and side chamber was always open, so that all running was voluntary. The floors of the wheels and of the side chambers consisted of evenly spaced cylindrical steel bars of 0.5 cm diameter. As noted above, a technical problem with one of the wheels meant that only 11 of the wheels could be used in this first experiment.

The chambers in which the control rats were held were similar to the side chambers of the activity wheels, but with acrylic floors covered with paper chips instead of metal bars. Custom software, written in LabVIEW®, controlled events within each wheel and recorded wheel turns and the timing of events.

Procedure All sessions in the wheels lasted for 90 min and rats remained in the colony room at all other times. Sessions for the Fixed-Early group started at 1000 h (the beginning of the dark cycle), while sessions for the Fixed-Mid group started at 1600 h (6 h within the dark cycle). The schedule used for the two Varied groups was one in which conditions changed (i.e., from Early to Mid or vice versa) either after a single or after 2 days. Thus, following an initial session starting at 1000 h, the Varied-Early group was given over Days 1–12 the sequence, Mid-Mid-Early-Early-Mid-Early-Mid-Mid-Early etc., while Varied-Mid group was given the sequence Early-Early-Mid-Mid-Early-Mid-Early-Early-Mid etc. (see Fig. 1). It may be noted that the two Varied groups were treated identically, apart from whether their first session was at the start or in the middle of the dark period.

Rats were transported in their cages to the wheel room through a short hallway, starting 20 min before their session was due to begin. During all handling, such as weighing and placing rats in the wheels, both the colony and the wheel rooms were illuminated with red light. Rats were weighed twice a week between 1430 and 1530 h in the colony room. The temperature in both the colony room and the wheel room was maintained at $22 \pm 1^\circ\text{C}$.

On the first day the Early groups were given their first 90-min session. Because recording of wheel turns was not reliable, the Mid groups were not run on this day, although this had been planned. By the following day the technical problem had been solved and the Mid groups were given their first session. From the next day, both the Early and the Mid groups were given their sessions every day for twelve days (designated Days 1–12).

Data analysis Only data from Days 1–12 were analyzed. The main analysis was a mixed $2 \times 2 \times (12)$ ANOVA applied to number of wheel turns per session, with Schedule (Fixed vs. Varied) and ToD (Early vs. Mid) as between-subjects factors and Session as the within-subjects factor. Further secondary analyses of body weight changes that also involved the control rats are described in the *Results* section.

Results

Mean daily wheel turns are shown in Fig. 1. It may be seen that there was a general increase across days and that, as predicted, this increase was greater in the Fixed than in the Varied

Fig. 1 Experiment 1. Mean ($\pm$ SEM) wheel turns for the Fixed-Early, Fixed-Mid, Varied-Early, and Varied-Mid groups over 12 days. To clarify the pattern shown by the Varied groups, wheel turns for all groups have been averaged across two sessions in which the Varied group were given the same condition, Early or Mid, on successive days (e.g., Sessions 1 and 2, 3 and 4), while showing the data for a single session when the condition was changed the next day (e.g., Day 5 and Day 6)

condition. This description was confirmed by the mixed ANOVA, whereby there was an overall linear trend across days, $F(1, 18) = 37.55, p < .001$, and an interaction between Schedule and Days, $F(1, 18) = 5.53, p = .03$. In addition, there was a three-way interaction between Schedule, ToD, and Days, $F(1, 18) = 6.18, p = .02$; inspection of Fig. 1 suggests that this interaction indicates that in early sessions the increase in wheel turns in the Fixed-Mid group was more rapid than in the Fixed-Early group.

The finding of an overall greater amount of running in the Fixed-Mid than in the Fixed-Early group suggests a ToD effect that was also seen in the Varied groups. Inspection of Fig. 1 suggests that rats in both Varied groups ran more in their Mid sessions than in their Early sessions. To examine this possibility, wheel turn counts from both Varied groups were separately averaged for Early sessions and Mid sessions across the experiment, as shown in Fig. 2. A 2×2 ANOVA (Group $\times$ ToD) applied to these data found both a main effect of ToD, $F(1, 20) = 82.14, p < .001$, confirming that, overall, these rats ran more in sessions held in the middle of the dark period than in sessions held early in this period, and also a main effect of Group, $F(1, 20) = 58.30, p < .001$, plus an interaction between Group and ToD, $F(1, 20) = 4.82, p = .04$. As seen in Fig. 2, the Group main effect can be attributed to more running overall in the Varied-Mid group than the Varied-Early group, and the interaction indicated that the difference in running between Early and Mid sessions was greater in the Varied-Mid group than that of the Varied-Early group. As these two groups differed only in whether their first wheel session was early or in the middle of the dark period, the latter effects are difficult to explain.

Changes in body weight were measured in terms of percentage gain from the start to the end of the experiment. The mean values for each of the six groups are shown in Fig. 3. As suggested by this figure, the smallest weight gain was shown

Fig. 2 Experiment 1. Mean ($\pm$ SEM) daily wheel turns per session for Early and Mid sessions in the two Varied groups. *** indicates a within-group difference at the level $p < .001$

by the group that ran the most, the Fixed-Mid group, and the largest gains were shown by the inactive Control groups. These data were analyzed in a 3×2 ANOVA (Group $\times$ ToD). This found a main effect of Group, $F(2, 26) = 9.64$, $p = .001$, and an interaction between Group and ToD, $F(2, 26) = 6.40$, $p = .006$, but no main effect of ToD, $F(1, 26) = 4.04$, $p > .05$. Two post hoc contrasts were conducted on these data. After controlling FER at .05 using the Scheffe procedure, rats in the Control groups gained more weight than those in the running groups (Varied and Fixed), $F(1, 26) = 11.39$, $p = .002$, and rats in the Varied groups gained more weight than those in the Fixed groups, $F(1, 26) = 7.11$, $p = .009$. Pairwise comparisons confirmed that rats in the Fixed-Early group gained significantly more weight than those in the Fixed-Mid group, $p = .001$, whereas no differences were found in weight gains between the Varied-Early and the Varied-Mid, $p > .05$, or between the Control-Early and the Control-Mid, $p > .05$.

Discussion

The main and novel result from Experiment 1 was that wheel turns in the Fixed condition increased more rapidly than in the Varied condition, as predicted. A further result was that rats ran more in sessions held in the middle of the dark period than in Early sessions. This effect was examined again in Experiment 2 and is discussed in the *General discussion*.

As for weight gain, the results were consistent with those from previous reports that rats given access to activity wheels gain less weight than inactive controls (e.g., Looy and Eikelboom, 1989) and with the report of a negative correlation between the amount that a rat runs and its gain in body weight (Afonso & Eikelboom, 2003).

Fig. 3 Experiment 1. Mean ($\pm$ SEM) weight gain over 14 days as a percentage of initial body weight at the beginning of the experiment for all six groups. * indicates a between-group difference significant at the level $p < .05$

Experiment 2

Towards the end of Experiment 1 the number of wheel turns made by the Fixed-Early group approached that of the Fixed-Mid group (see Fig. 1), thus suggesting that, if the experiment had been extended, asymptotic amounts of running would be similar in the two groups. One aim of this second experiment was to examine this possibility. A second aim was to test whether differences between active and inactive animals in weight gain would also be seen in chow consumption. In pursuit of these aims, the main differences between this and the first experiment were to extend the number of daily running sessions to 18 and to house rats individually so that chow consumption by each rat could be measured. In addition, younger rats that were experimentally naïve were employed in this second experiment.

The same 2×2 factorial design as in Experiment 1 was used for the main part of this experiment: One factor was Schedule (Fixed vs. Varied) and the second factor was whether the first experimental session took place early or in the middle of the dark period (Early vs. Mid). Thus, there were again four main groups: Fixed-Early, Fixed-Mid, Varied-Early, and Varied-Mid.

In order to analyze effects of running on weight gain and chow consumption, there were again two further groups that served as inactive controls. They differed only as to whether they were held in the wheel room in the early part of the dark period or in the middle.

Method

Subjects Thirty-two male Sprague Dawley rats were purchased from ARC Perth, WA, Australia. On arrival they were housed four to a cage but 5 days later – the day before the experiment started – they were transferred to individual housing. This consisted of partitioning the regular ventilated cages into two halves that were separated by transparent dividers. These enabled a rat to see, hear, and smell the other rat in its cage but not engage in physical contact. The rats were 9 weeks old at the start of the experiment. Besides the single housing, all other conditions were as in Experiment 1.

Apparatus All 12 of the activity wheels described for Experiment 1 were used.

Procedure Matching for bodyweight, six rats were allocated to each of the four main groups and four rats were allocated to each of the two control groups. The daily procedure was the same as that of Experiment 1; daily 90-min sessions – including Day 1 in this experiment – started either at 1000 h or at 1600 h. Rats and chow were weighed between 1145 and 1400 h every 4 days.

Results

Mean daily wheel turns for each of the main groups are shown in Fig. 4. It may be seen that these results were in general similar to those found in Experiment 1 (see Fig. 1). The Varied groups showed little overall increase and displayed the pattern of greater amounts of running in Mid sessions than in Early sessions that were shown by the equivalent groups in Experiment 1. Furthermore, the amount of wheel turns by the Fixed-Mid group increased steadily throughout the eighteen days and showed no sign of reaching an asymptote, as seen in the equivalent group in Experiment 1. The exception was the Fixed-Early group; it may be seen in Fig. 4 that running by this group did not increase any more than running in the Varied groups.

This description of the data shown in Fig. 4 was largely confirmed by the following analyses. A mixed $2 \times 2 \times (18)$ ANOVA, with Schedule (Fixed vs. Varied), ToD, and Day as factors, revealed an overall linear trend across days, $F(1, 20) = 12.58$, $p = .002$, and this trend interacted with ToD, $F(1, 20) = 5.19$, $p = .03$. This interaction confirms that in general the Mid groups increased running more than the Early groups. As noted above, inspection of Fig. 4 suggests a three-way interaction whereby wheel turns by the Fixed-Mid group increased faster than those by the Fixed-Early group, with no overall difference between Varied-Early and Varied-Mid groups; however, no significant interaction between Schedule, ToD, and Days was found, $p > .05$. Unlike in Experiment 1, no interaction between Schedule and Days was detected, $p > .05$.

Fig. 4 Experiment 2. Mean ($\pm$ SEM) wheel turns for the Fixed-Early, Fixed-Mid, Varied-Early, and Varied-Mid groups. As in Fig. 1, wheel turns for all groups have been averaged across two sessions in which the Varied group were given the same condition, Early or Mid, on successive days (e.g., Sessions 2 and 3, Sessions 4 and 5), while showing the means for a single session when the condition for the Varied groups was changed the next day (e.g., Session 6 and Session 7)

Analysis of running in the Varied groups was similar to that in Experiment 1. Wheel turns during sessions early in the dark period were averaged separately from those in the middle of this period, as shown in Fig. 5. As in the previous experiment, rats in both groups ran more in the middle of the dark period than early in this period. This was confirmed by a 2×2 mixed ANOVA (Group $\times$ ToD) that revealed a main effect of ToD, $F(1, 20) = 68.11$, $p < .001$. This analysis also revealed an interaction between Group and ToD, $F(1, 20) = 8.88$, $p = .005$, indicating that the ToD effect was greater in the Varied-Early group than in the Varied-Mid group. No main effect of Group was found, $F < 1$. Pairwise comparisons were applied to show that rats ran more in the middle of the dark period for both Varied groups, $ps < .001$.

Mean percent weight gain from start to finish of the experiment is shown in Fig. 6A. It may be seen that, as in the previous experiment, the four main groups that were given daily sessions in the activity wheels gained less weight than the inactive control groups. This was confirmed by a 3×2 ANOVA (Group $\times$ ToD) applied to these data; this revealed a main effect of Group, $F(2, 26) = 14.731$, $p < .001$, and an interaction between Group and ToD, $F(2, 26) = 6.338$, $p < .01$, but no main effect of ToD, $F < 1$. Two post hoc contrasts, after controlling family-wise error rate (FER) at .05 using the Scheffé procedure, confirmed that the Control groups gained more weight than those in the running groups, $F(1, 26) = 25$, $p < .05$, but found no difference between the Fixed and Varied groups, $F(1, 26) = 1.92$, $p > .05$. Pairwise comparisons found that rats in the Control-Mid group gained more weight than those in the Control-Early group, $p = .01$. No significant differences in weight gains were found between the Varied-Early and the Varied-Mid groups, $p > .05$, or between the Fixed-Early and Fixed-Mid groups, $p > .05$.

Fig. 5 Experiment 2. Mean ($\pm$ SEM) daily wheel turns per session by the Varied groups for sessions early in the dark period (Early condition) and sessions in the middle of this period (Mid condition). *** indicates that the within-subject differences were significant at the $p < .001$ level

Fig. 6 Experiment 2. **A.** Mean ($\pm$ SEM) weight gain over 17 days as a percentage of initial bodyweight for all six groups. **B.** Mean total food consumptions over 16 days by all six groups. * indicates a between-subject difference at the $p < .05$ level of significance

The total amount of food a rat consumed over 16 days, averaged for each group, is shown in Fig. 6B. It may be seen that the pattern of results was very similar to that for weight gain shown in Fig. 6A, to the extent that rats in the inactive control groups ate more than those in the four main groups. A 3×2 ANOVA (Group $\times$ ToD) revealed both a main effect of Group, $F(2, 26) = 14.01$, $p < .001$, and an interaction between Group and ToD, $F(2, 26) = 4.99$, $p = .015$, but no main effect of ToD, $F(1, 26) = 1.134$, $p > .05$. Two post hoc contrasts of the kind applied to the weight data were also applied to these food intakes. After controlling FER at .05 using the Scheffe procedure, these confirmed that rats in the Control groups consumed more food than those in the main groups, $F(2, 26) = 27.47$, $p < .05$, but found no difference between the Fixed and Varied groups, $F < 1$. Pairwise comparisons

revealed that the Fixed-Early group ate more than the Fixed-Mid group, $p = .005$, whereas no significant differences were found between the Varied-Early and Varied-Mid groups or between the Control-Early and Control-Mid groups, both $p > .05$.

Discussion

The use of younger rats that were individually housed in this experiment yielded results that in general replicated the pattern of results found in Experiment 1. Notably, a steady increase in running was found in the Fixed-Mid group and, overall, rats ran more in the Mid sessions than in Early sessions. The exception in this second experiment was the Fixed-Early group that showed no increase in running. The possible reason for this and for the general difference found between Early and Mid sessions is addressed in the *General discussion*.

Experiment 2 also replicated the finding that rats given daily sessions in the wheels gained less weight than inactive controls. The new results were obtained from monitoring each rat's food intake. These data showed that the inactive rats in the Control groups consumed more food than those in the running groups. This finding is consistent with previous reports (Lattanzio & Eikelboom, 2003; Looy & Eikelboom, 1989) and strongly suggests that the slower weight gain in the wheel-running rats was because they ate less.

General discussion

The main aim of this study was to test the prediction that giving rats their wheel sessions at a fixed time of day would promote entrainment of their circadian rhythm, as reflected by a greater increase in running over days than in rats given their session at varied times of day. This prediction was fully confirmed for the older and group-housed rats tested in Experiment 1 but confirmed only for the younger and individually housed rats in Experiment 2 that were run in the middle of the dark period (Fixed-Mid group). Previous studies have found that increases in running over sessions are less likely to occur with short (< 2 h) periods of wheel access (Cordony, Chow & Boakes, 2019; Eikelboom & Lattanzio, 2003). This suggests that stronger evidence for the above prediction would have been found if daily sessions had lasted longer than the 90 min used in both experiments.

A robust result from both experiments was that, when given their 90-min wheel session in the middle of the dark period, rats ran more than in the first 90 min of the dark period. This ToD effect was as strong for the rats in Experiment 2 that had experienced the light-dark cycle in the colony room for three weeks as for the rats in Experiment 1 that had lived with this cycle for about 10 weeks. This Early-versus-Mid effect is inconsistent with at least one previous report. For example, in the experiment reported by Holmes et al. (2004) that was described in the *Introduction*, mice given 3-h daily access to wheels early in the dark period ran as much as those given access in the middle of this period. It may be noted that no other experiment appears to have contained a within-subject comparison of running at different times during the dark period.

Over a 24-h period on a 12h/12h light/dark cycle rats that are confined to their home cages, with unrestricted access to chow and no access to activity wheels, normally eat little during most of their light period but begin a major bout of eating towards the end of this period, a bout that continues well into their dark period (e.g., Mistlberger, 1994; Rosenwasser, Boulos, & Terman, 1981). The timing of Early wheel sessions in both of the present experiments was one in which, prior to these sessions, rats were transported to the wheel room and placed in the cages adjoining the activity wheels during a period of 20 min before the end of the light cycle; the wheels were unlocked at 1000 h, the start of the dark period. Thus, these events occurred at a time when the rats would normally have a major meal.

It is feasible that the Early-versus-Mid effect reported here results from competition between two motivational systems, with “wanting”: food interfering with “wanting” to run (Berridge & Robinson, 2016). In Experiment 1 the Fixed-Early rats started running less than the Fixed-Mid rats but eventually caught up; see Fig. 1. This could have resulted from the feeding pattern of the Fixed-Early rats shifting so that these rats ate earlier, that is, well before they were transported to the wheel room. On the other hand, the irregular timing for the Varied rats would not have promoted this shift. This proposal leaves open the question of why such adjustment did not occur with the Fixed-Early group in Experiment 2.

An alternative, and related, possibility is that, because the Fixed-Mid group had consumed more food prior to their wheel session than the Fixed-Early group, they would have greater energy available to sustain high rates of running. An experiment of the present kind, in which the times when, and amounts that, rats ate were recorded, could be interesting in the light of both of these possibilities.

As noted earlier, previous experiments have found that rats given access to activity wheels gain less weight than inactive controls (Lattanzio & Eikelboom, 2003; Tokuyama et al., 1982). The present data on body weight increases are consistent with these reports, as is the finding in Experiment 2 that active rats ate less than inactive rats, suggesting that the reduction in weight gain was caused by a reduction in food intake (cf. Looy & Eikelboom, 1989).

In summary, results from these two experiments generally supported the prediction that providing rats with daily wheel-running sessions at the same time each day would lead to greater increases in the amount these rats ran than in rats given sessions at varied times of day. As such, this supports the hypothesis that increases in running at least partly reflect improved integration of running into a rat's daily cycle of activities. As such it counts against the claim that increased running by rats represents a form of addiction. Unexpectedly a ToD effect was found whereby rats given sessions at the start of their 12-h dark cycle ran less than rats whose sessions started 6 hours later. Rats with wheel access consumed less food and

gained less weight than inactive controls. It is recommended that any future experiments on this topic use longer wheel sessions and monitor the times at which rats eat.

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The complete data set from both experiments are available from RAB and will be made publicly available

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