

Positive Automaintenance in SHR and WKY Rats: Faster Acquisition of Lever-Pressing in the Former Strain Suggests Differences in Impulsivity between Strains ¹

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Abstract

The spontaneously hypertensive rat (SHR) has been compared with the normotensive Wistar-Kyoto (WKY) rat when developing rodent models of attention deficit hyperactivity disorder (ADHD). Between-strain differences in response acquisition have been attributed to deficits in attention in the former but not the latter strain. However, conflicting results have been obtained by research that examined differences in the acquisition of lever-pressing between SHR and WKY rats. This raises the possibility that impulsivity, rather than deficits of attention, is the mechanism accounting for differences between strains. The present study used Williams and Williams' (1969) positive automaintenance procedure to examine lever-pressing acquisition in SHR and WKY rats. In addition, possible strain differences in the maintenance of that behavior were examined using a concurrent-chains procedure. Results of the former procedure showed retarded acquisition of lever-pressing in the WKY rats when compared to the SHRs, suggesting differences in impulsivity between strains. Results of latter procedure showed no differences in the maintenance of lever-pressing between strains, nor were there differences in preference across conditions. These results have implications for the development of rodent models of ADHD using SHR and WKY rats as subjects.

Key words: *SHR, WKY, response-acquisition, ADHD, rats.*

Resumen

La rata hiper-sensitiva espontáneamente (SHR) se compara con la rata control sensitivo-normal (WKY) en el desarrollo de modelos de déficit de atención por hiperactividad (ADHD). Las diferencias entre estas cepas en la adquisición de la respuesta de presionar una palanca se atribuyen a déficits de atención en la rata SHR. Estudios que han examinado diferencias en la adquisición de esa respuesta, no muestran resultados consistentes con esta idea. Lo cual sugiere que es la impulsividad y no la deficiencia en atención lo que caracteriza a la rata SHR. En el presente estudio utilizó el procedimiento de auto-mantenimiento positivo de Williams y Williams (1969) para examinar posibles diferencias entre cepas SHR y WKY en la adquisición de la respuesta de presionar en una palanca y su mantenimiento en un programa concurrente encadenado. Los resultados del primer procedimiento mostraron en las ratas WKY un retardo en la adquisición de esa respuesta al compararse con las ratas SHR, sugiriendo diferencias en impulsividad entre esas cepas. Pero no se observaron diferencias en el mantenimiento de la respuesta de presionar la palanca en diferentes condiciones del concurrente encadenado. Lo cual tiene implicaciones para la formulación de modelos de déficit de atención por hiperactividad (ADHD) que utilizan esas cepas como sujetos.

¹ La referencia de este artículo en la Web es: <http://conductual.com/content/positive-automaintenance-shr-and-wky-rats>

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Palabras clave: *SHR, WKY, ADHD, adquisición, respuestas, ratas.*

The spontaneously hypertensive rat (SHR) has been compared with the normotensive Wistar-Kyoto (WKY) rat when developing rodent models of attention deficit hyperactivity disorder (Sagvolden, 2000). The rationale for this research is that the SHR behaves in ways that are similar to those observed in humans diagnosed with attention deficit hyperactivity disorder (ADHD), who typically show inability to pay attention and increased impulsivity in decision making tasks (Adriani, Caprioli, Granstrem, Carli, and Laviola, 2003). Consistent with these ideas, SHRs have been shown to choose more impulsively than the WKY rats in studies using inter-temporal choice procedures (e.g., Fox, Hand, Reilly, 2008). Experimental efforts directed to identify behavioral and neurological variables controlling lever-pressing acquisition in SHR and WKY rats warrant in research developing rodent models of ADHD.

Related research in inter-temporal choice using Lewis (LEW) and Fischer 344 (F344) rat strains as subjects, has shown that the former strain made more impulsive choices than the latter strain (e.g., Anderson & Diller, 2010; Huskinson, Krebs, & Anderson, 2012; Anderson & Woolverton, 2005; Madden, Smith, Brewer, Pinkston, & Johnson, 2008; Stein et al., 2012).

Moreover, it has been revealed that LEWs acquired lever pressing faster and responded at higher rates than the F344s in procedures that used Brown and Jenkin's (1968) autoshaping technique to establish lever-pressing (Kearns, Gomez-Serrano, Weiss, & Riley, 2006). This finding was corroborated in studies that used a tandem fixed-ratio one (FR1) fixed-time (FT) 20 s schedule of reinforcement to establish lever pressing for food (Anderson and Elcoro, 2007), showing that a greater number of LEWs (5/8) acquired lever pressing behavior compared to the F344s (2/8).

Studies looking at lever pressing acquisition in SHR and WKY rats used a tandem FR1 differential reinforcement of other behavior (DRO) 15-s schedule, where one lever-press initiated a 15-s unsignaled delay and responses during the DRO reset the delay; the results showed retarded acquisition of lever-pressing in the SHR rats, making lower response rates and earning fewer reinforcers than the WKY rats (Hand, Fox, & Reilly, 2006). These findings, however, were in dispute with those obtained in a study using a similar tandem FR1 DRO 15-s schedule in which the delay to the reinforcer delivery was signaled by the illumination of a houselight, showing no differences in the acquisition of lever-pressing between strains (Hand, Fox, & Reilly, 2010). Consequently, further research aimed at consolidating these findings is necessary to understand the underlying mechanisms determining strain differences in the acquisition of lever-pressing.

The present study used a positive automaintenance procedure, similar to that of Williams and Williams (1969, Experiment III), to establish lever-pressing behavior in SHR and WKY rats. In this procedure responding to the signal does not cancel it, nor does it reduce the delay to the delivery of the food-reinforcer, differing from Brown and Jenkins' (1968) autoshaping method.

Sing-tracking behaviors have been observed in different species (Hearst & Jenkins, 1974). In rats, research shows that they track, approach, and make contact with a stimulus such as the insertion of a lever into the chamber signaling the delivery of food reinforcers (Tomie, Lincks, Nadarajah, Pohorecky, & Yu, 2012). While making contact with the lever and pressing on it is not required to produce the reinforcer, rats continue to show this behavior and recovers rapidly after extinction, suggesting that it is difficult to suppress (Davey, Oakley, & Cleland, 1981; Kerns & Weiss, 2007), demonstrating a form of reduced inhibitory control or impulsivity (Tomie, Grimes, & Pohorecky, 2008) which has been used to predict autoshaping (Tomie, Aguado, Pohorecky, & Benjamin, 1998). The reduced inhibitory control showed by

human and nonhuman animals has been interpreted as an impulsive action or motor impulsivity mechanism to explain poorly-timed responding (Evenden, 1999).

The positive automaintenance procedure is a suitable technique to assess between strain differences in lever-pressing acquisition that may be attributable to lack of attention or vigilance (i.e., poor sign-tracking), which is a critical factor in developing rodent models of ADHD. If lack of attention is the underlying mechanism accounting for retarded lever-pressing acquisition, then the WKY rats should exhibit faster lever-pressing acquisition than the SHR rats that presumably show lack of attention. However, if attention is not the crucial factor in determining differences in the acquisition of lever-pressing, there should be no differences between the SHR and WKY rats in the acquisition of this behavior. Alternatively, if the WKYs show retarded lever-pressing acquisition in the positive automaintenance procedure compared to the SHRs, then impulsivity is the mechanism underlying differences between these strains. It has been shown that rats tracking signals exhibit more impulsive action than impulsive choice (Flagel, Robinson, Clark, Clinton, Watson, Seeman, Phillips, & Akil, 2010; Lovic, Saunders, Yager, & Robinson, 2011); the latter has been interpreted as a category of cognitive impulsivity (Dalley, Everitt, & Robbins, 2011).

In addition, the present study examined possible between strain differences in responding to a concurrent-chains procedure where, in different conditions, entries to the terminal link were arranged by response independent and response dependent schedules of reinforcement. The idea was to identify plausible differences in response output between strains that can be attributed to different levels of impulsivity. If the SHRs are more impulsive than the WKY rats, then the former strain is expected to respond at higher rates across conditions. However, if initial between strains differences in impulsive action, as estimated by the acquisition of lever-pressing, occur early in training (first 10-sessions of positive automaintenance procedure) and disappear with extended experience in concurrent chains-procedures, as shown in studies examining impulsive choice in LEW and F344 rats (Aparicio, Hughes, & Pitts, 2013), then in the present study the SHRs and WKYs should respond to the initial-link levers at comparable levels across conditions of the concurrent-chains procedure.

Method

Subjects

The subjects were eight male SHRs (numbered 201-208) and eight WKYs (numbered 101-108) rats (strains SHR/NCrl and WKY/NCrl; Charles River laboratories, Wilmington, MA). Upon arrival, the 53 day old rats were separated into individual plastic cages with free access to food and water in a temperature-controlled colony room providing 12:12 hr light/dark cycle (lights on at 0700). An ad libitum feeding regimen of Purina Lab Chow was used for six weeks, allowing habituation to the vivarium. The day before the start of the study, the feeders of all cages were emptied and the rats were placed on a regimen of food restriction (no weight reduction was attempted); supplementary feedings of Purina® Chow of approximately 10 g (+/- 2 g) were provided to each rat at the end of the session. The weights of the SHR and WKY rats at the beginning of the experiment ranged from 249 to 286 g and from 262 to 287 g, respectively. All rats were 90 days old at the beginning of the study and experimentally naïve.

Apparatus

All sessions were conducted using eight equally equipped Coulbourn Instruments (Whitehall, PA) modular chambers (E10-11R TC), enclosed in sound-attenuating boxes (E10-23) with exhaust fans that from the outside measured 51.4 cm high, 79.4 cm wide, and 53.3 cm deep. Each modular chamber

measured 33 cm high by 30 cm wide by 30 cm deep; the sidewalls and ceilings were constructed of Plexiglas, the front and rear walls of aluminum, and the floors were of stainless steel (E10-18NS). Each front panel was equipped with two retractable levers (E23-17RA) measuring 3.3 cm wide, protruding 2 cm from the wall, and required a force of .25 N to operate; each lever was 7 cm above the floor and 3 cm from its respective left and right sidewall. Two 24-V DC stimulus lights (H11-03R) were installed 3.5 cm above the levers. A food cup (E14-01R), 4 cm high by 3 cm wide, was centered 4.5 cm from the left- and 4.5 cm from the right-lever at 2 cm from the floor. A food dispenser (H14-23R) located behind the front wall delivered 45-mg grain pellets (BioServ®) into the food cup. A third non-retractable lever (H21-03R), requiring a force of .25 N to operate, was centered on the rear wall of each chamber 7 cm above the floor. A 24-V DC houselight (H11-01R) centered on the rear wall, 19 cm above the non-retractable lever, provided the illumination of the chamber. A 8 cm high by 7 cm wide speaker (H12-01R), mounted on the rear wall at 20 cm from the floor, 1 cm from the left sidewall, and 6.5 cm from the house light, was connected to a white noise generator (E12-08) providing a constant white noise 20 kHz (+/- 3 dB). All experimental events were programmed and data recorded in a separate room by Windows®-controlled computers using Coulbourn Instruments® software (Graphic State Notation, version 3.03) and interfacing equipment operating at .01-s resolution.

Procedure

Positive Automaintenance

A procedure similar to that of Williams and Williams (1969, Experiment III) was used to establish lever pressing. Each session consisted of sixty trials arranged according to two variable time 60-s schedules (VT 60-s) operating concurrently (Conc VT 60-s VT 60-s), with inter-trial intervals set by a constant-probability algorithm similar to that of Catania and Reynolds (1968). In each trial, either the left or the right lever (randomly selected) was extended into the chamber with the light above it turned on for 15-s. Responses on the extended lever had no scheduled consequences, but were recorded. The trial ended by delivering a food pellet, turning off the light above the lever, and retracting it from the chamber. During the inter-trial interval (i.e., VT 60-s), the same or the other lever could be selected and extended in the next trial. A non-retractable rear lever was permanently available in the chamber with no scheduled consequences whatsoever, but responses on that lever were also recorded during the session. The session ended with the 60th trial and was conducted at the same time every day. The procedure continued for 30 consecutive sessions.

Concurrent chains-procedure

After the positive auto-maintenance procedure was completed, the SHR and WKY rats were exposed to a concurrent chains procedure.

Condition A

Each session consisted of a series of choice cycles. The session began with the illumination of the houselight. To start the initial link of the concurrent chain procedure, one press on the rear lever caused the two front levers to extend into the chamber, illuminating the lights above. On average every 35 s, two random time (RT) response independent schedules arranged entries to the terminal links. One RT 35-s was associated with the left lever and the other RT 35-s schedule with the right lever. To generate the random time schedule, a probability generator was set to .05, sampling every 4-s to select either the left or the right lever as operative; each lever was selected approximately an equal number of times during the session. When an entry was set up for the left lever, the procedure automatically advanced to the terminal link retracting the right lever and turning of the light above it. The first response on the left lever (fixed-

ratio 1, or FR1) produced a food pellet and re-started the cycle retracting the left lever and turning off the light above it. Similarly, when a RT 35-s schedule arranged an entry for the right lever, the procedure automatically advanced to the terminal link retracting the left lever and turning of the light above it. One response on the right lever produced a food pellet retracting the right lever, turning off the light above it, and re-starting the cycle of the concurrent chains schedule. Technically, the schedule of reinforcement in condition *A* was a concurrent-chains FR1 (rear lever) RT 15-s (initial link) FR1 (terminal link). Sessions ended with the 60th food delivery and were conducted at the same time every day to complete 10 consecutive sessions.

Condition B

It was similar to condition *A*, the only difference was that a response dependent initial link instead of a response independent initial link concurrent-chains procedure was used in condition *B*. Accordingly, when an entry to the terminal link was set up for the left lever, one response on that lever was required to advance the procedure to the terminal link, causing the right lever to retract and turning off the light above it. After that, the next response on the left lever produced a food pellet and re-started the cycle retracting the left lever and turning off the light above it. Correspondingly, when a RT 35-s schedule arranged an entry for the right lever, the first response on that lever advanced the procedure to the terminal link, causing the left lever to retract and turning off the light above it. The next response on the right lever produced a food pellet retracting the right lever, turning off the light above it, and re-starting the cycle of the concurrent chains schedule. Technically, the schedule of reinforcement in condition *B* was a concurrent-chains FR1 (rear lever) RI 15-s (initial link) FR1 (terminal link).

Sessions ended with the 60th food delivery and were conducted at the same time every day to complete 10 consecutive sessions for each condition. Redeterminations to conditions *A* and *B* were conducted for another 10 sessions each, completing an ABAB reversal within subject experimental design.

Data Analysis

Throughout both conditions the main dependent measure was the number of responses on the left and right levers. The data of all sessions were analyzed. A nonparametric statistical Mann-Whitney U-test examined differences between strains in cumulative number of responses emitted on the left, right, and rear levers. Paired Sample t-tests were used to determine significant differences within strain and between groups in number of responses emitted in the left and right lever across conditions. All nonparametric and hypothesis testing statistical tests, at the alpha level of .05, were implemented with Origin[®].

Results

Positive Auto-maintenance

Figure 1 shows the cumulative number of responses emitted on the left- (open circles) and right-lever (heavy lines) during the sessions of the positive auto-maintenance procedure. (Note logarithmic scale in the primary and secondary y-axis). The left column shows data for the SHR rats and the right column data for the WKY rats. All of the SHR rats pressed the left- or the right-lever at least once during the first session of the positive auto-maintenance procedure, some rats emitted 10 or more responses (206 and 202), and one rat (207) 100 responses on each lever. For the SHR rats, the number of responses in left and right levers increased with each number of sessions, reaching cumulative responses ranging from 100 to 1000 or more with the 30th session of the positive auto-maintenance procedure. In contrast, the WKY rats made fewer responses on the left and right levers in sessions 1-10 of positive auto-maintenance. For

the WKY rats, the right column of Figure 1 shows retarded acquisition of lever pressing. It not was until session 11 that the WKY rats began to respond consistently on the left and right levers and continued responding for the next 19 sessions, reaching levels of cumulative responses that were of similar numbers to those the SHR rats reached in comparable sessions (but see WKY-104).

Figure 1. Cumulative number of responses emitted on the left- (open circles) and right-lever (heavy line) by the SHRs (left column) and WKYs (right column) against number of session of the positive automaintenance procedure.

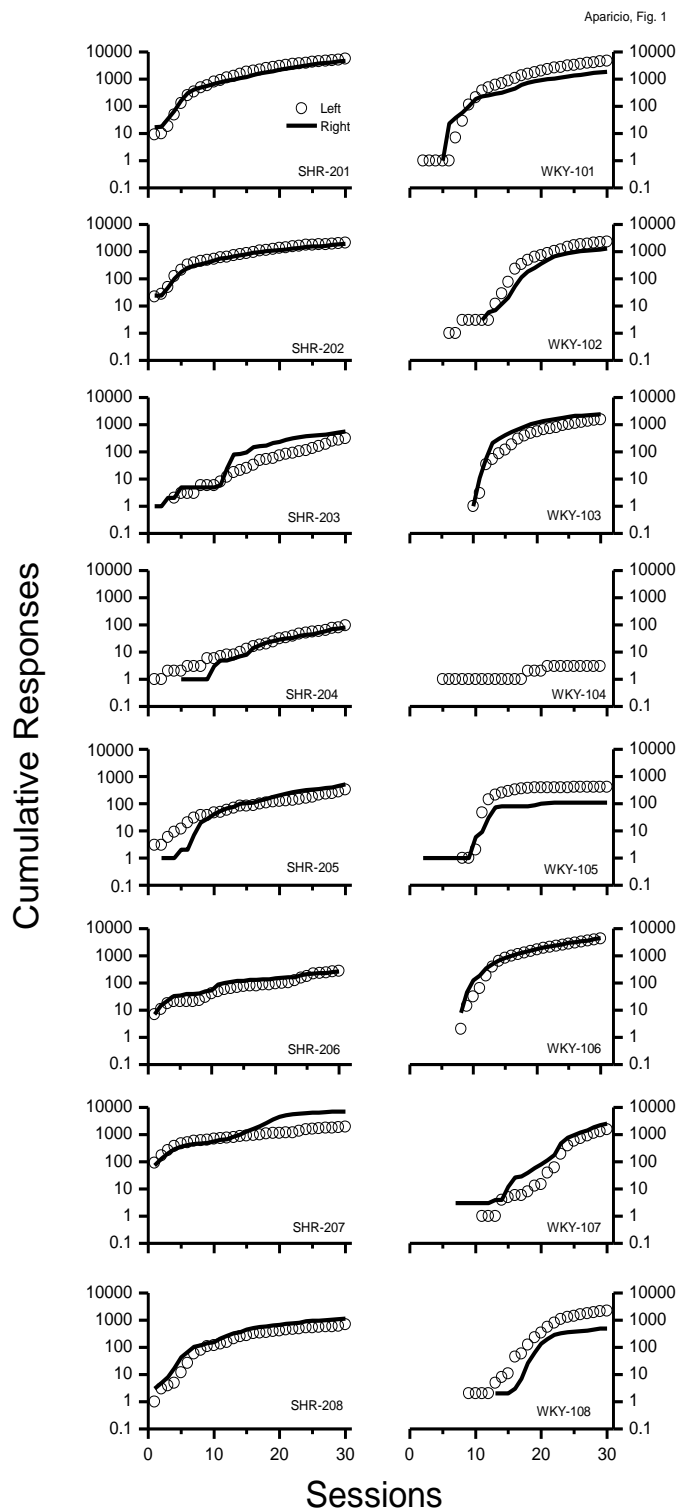
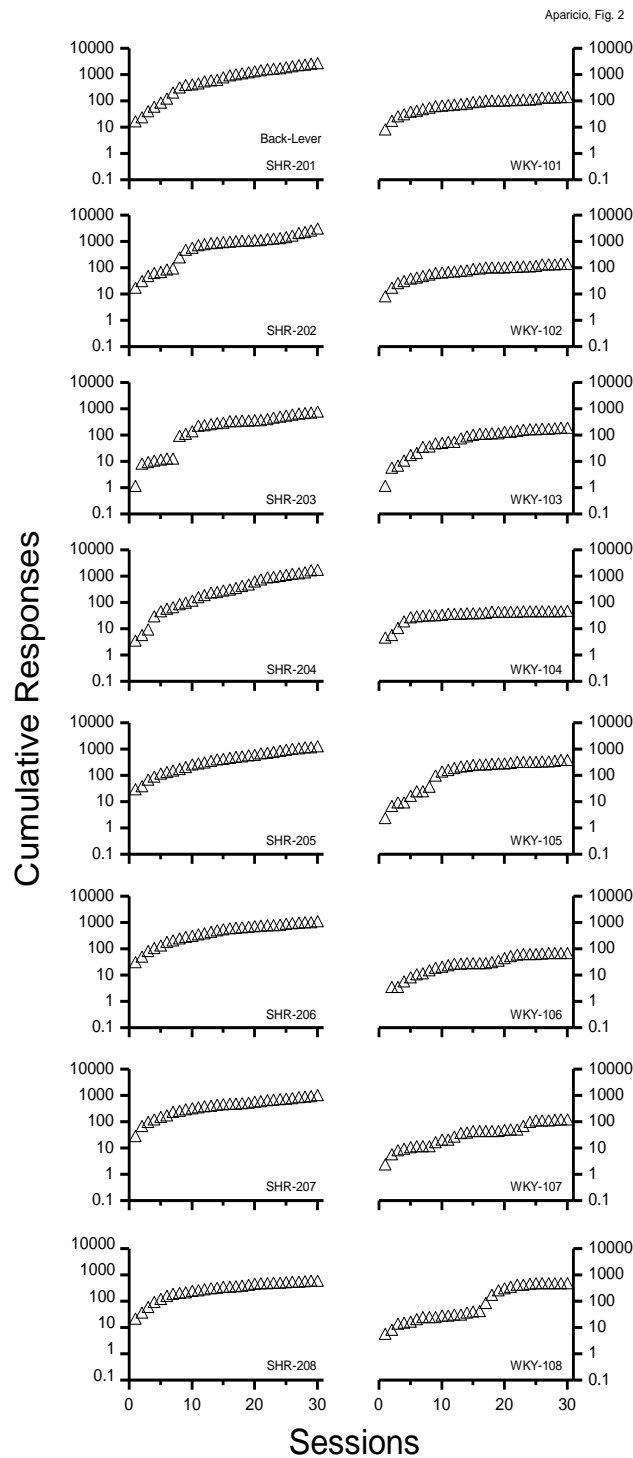


Figure 2. Cumulative number of responses emitted on the rear lever against number of session of the positive automaintenance procedure. Other details as in Figure 1.



Statistical analyses (via Mann-Whitney U test) showed significant differences between SHR and WKY rats in the cumulative number of responses emitted on the left lever in sessions 1 ($U = 60, p = 0.001$), 2 ($U = 59, p = 0.003$), 3 ($U = 59.5, p = 0.002$), 4 ($U = 64, p = 0.001$), 5 ($U = 64, p = 0.001$), 6 ($U = 64, p = 0.001$), 7 ($U = 62, p = 0.002$), 8 ($U = 60.5, p = 0.003$), 9 ($U = 57, p = 0.010$), 10 ($U = 57, p = 0.010$), and 11 ($U = 53, p = 0.031$). Further statistical comparisons revealed no significant differences

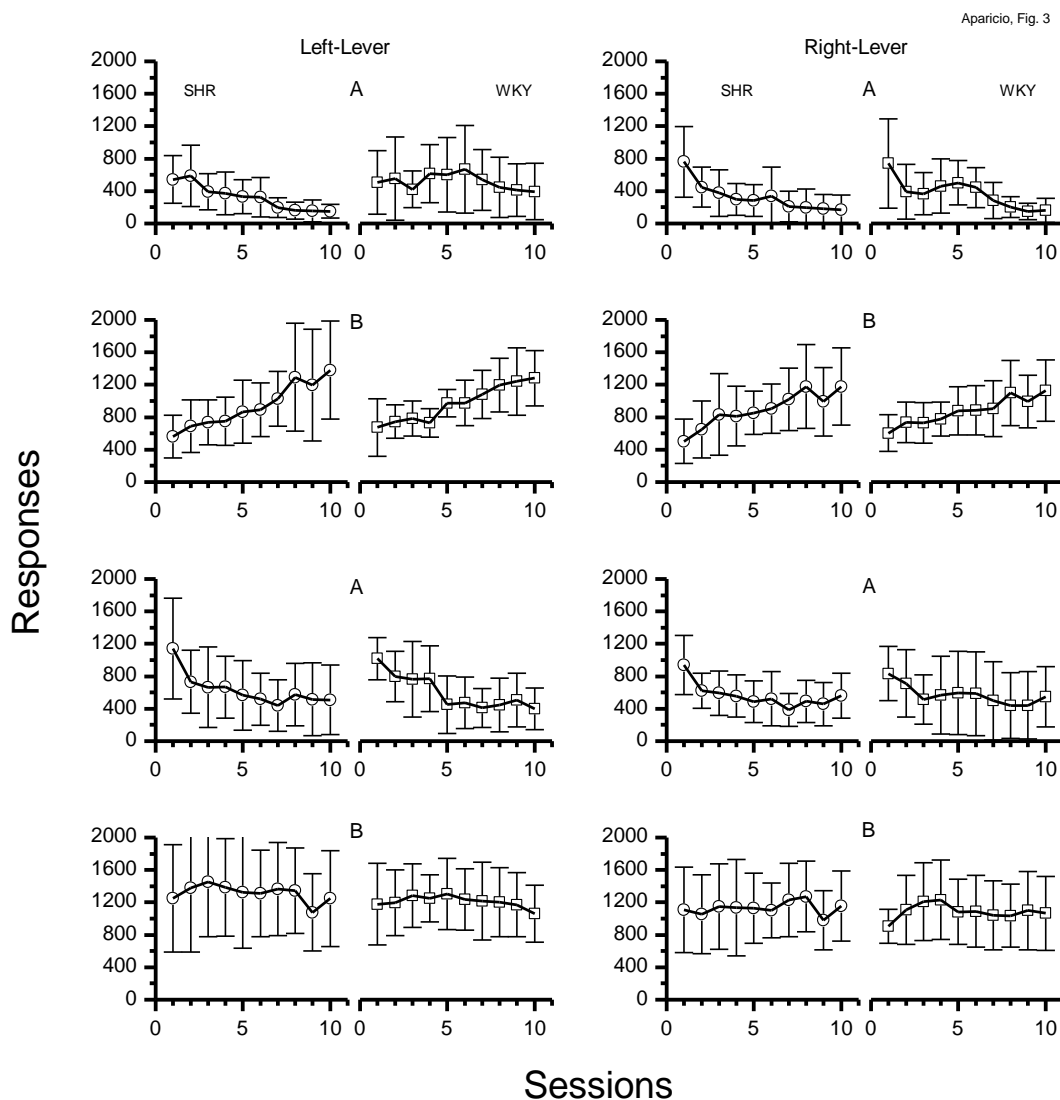
between SHR and WKY rats in the cumulative number of responses emitted on the left lever in sessions 12 to 30. Correspondingly, there were differences between SHR and WKY rats in the cumulative number of responses emitted on the right lever in sessions 1 ($U = 56, p = 0.005$), 2 ($U = 58, p = 0.003$), 3 ($U = 59, p = 0.003$), 4 ($U = 59, p = 0.003$), 5 ($U = 63, p = 0.001$), 6 ($U = 60.5, p = 0.003$), 7 ($U = 59.5, p = 0.004$), 8 ($U = 56.5, p = 0.011$), 9 ($U = 55.5, p = 0.015$), and 10 ($U = 52.5, p = 0.035$). Also, statistical comparisons of the data of cumulative number of responses emitted on the right lever showed no significant differences between SHR and WKY rats in sessions 11 to 30.

For the individual SHR and WKY rats, Figure 2 plots (left and right columns, respectively) the cumulative number of responses emitted on the rear lever against the 30 sessions of the positive auto-maintenance procedure. Figure 2 clearly shows that the SHR rats emitted more responses on the rear lever than the WKY rats across all sessions of positive auto-maintenance. Additional comparisons using a Mann-Whitney U test, showed that the cumulative number of responses that the SHR rats emitted on the rear lever was significantly higher than that emitted by the WKY in sessions 1 ($U = 53.5, p = 0.027$), 2 ($U = 56, p = 0.013$), 3 ($U = 55, p = 0.018$), 4 ($U = 57.5, p = 0.009$), 5 ($U = 58, p = 0.007$), 6 ($U = 58, p = 0.007$), 7 ($U = 58, p = 0.007$), 8 ($U = 64, p = 0.001$), 9 ($U = 63, p = 0.001$), 10 ($U = 62.5, p = 0.002$), 11 ($U = 64, p = 0.001$), and 12 ($U = 63, p = 0.001$). Further statistical comparisons revealed significant differences between SHR and WKY rats in cumulative number of responses emitted on the rear lever for sessions 12 to 30 ($U = 64, p = 0.001$).

Concurrent chains-procedure

For the group data of the SHR and WKY rats, Figure 3 plots the number of responses emitted on the left lever (columns 1 and 2, respectively) and right lever (columns 3 and 4, respectively) during the initial link of the concurrent chains-procedure against the number of sessions arranged by the ABAB reversal experimental design. From top to bottom, the graphs show mean responses and error bars in conditions *A* and *B* and their redeterminations. The first row shows that the average numbers of responses that the SHRs (circles) and WKYs (squares) emitted on the left- (mean across sessions of 321.4 and 515.6, respectively) and right-lever (mean across sessions of 325.7 and 370.5) in condition *A*, were lower than the average numbers of responses that the second row shows for condition *B* for the left- (mean across sessions of 939.1 and 968.3, respectively) and right-lever (mean across sessions of 892.3 and 874.5, respectively). The WKYs showed greater within-group variability than the SHRs across sessions of condition *A*. However, the opposite result was observed across sessions of condition *B*; the SHRs showed greater within-group variability than the WKYs. Redeterminations to conditions *A* and *B* replicated results obtained in the original determinations; in the redetermination to condition *A* (third row), groups' average numbers of responses emitted on the left- (mean across sessions of 632.7 and 603.4, respectively) and right-lever (mean across sessions of 561.2 and 573.2, respectively), were lower than groups' average numbers of responses emitted on the left- (mean across sessions of 1314.3 and 1210.6, respectively) and right-lever (mean across sessions of 1130.8 and 1087.3, respectively) in the redetermination to condition *B* (the fourth row of graphs). The within-group variability that the SHRs showed across sessions of the redeterminations to conditions *A* and *B* was of comparable levels to that showed by the WKYs across sessions of these redeterminations. These trends in group average number of responses were consistent with those the individual SHR and WKY rats emitted on the left- and right-levers in conditions *A* and *B* and their redeterminations. To facilitate comparisons across conditions, the data of responses on the left- and right-lever were used to compute response rates and these computations were plotted in Figure A1 (Appendix-A).

Figure 3. Groups' data of responses emitted on the left- (columns 1 and 2) and right-lever (columns 3 and 4) by the SHRs (circles) and WKYs (squares) on conditions *A* (first row), *B* (second row), and redeterminations to *A* (third row) and *B* fourth row) against number of session of the concurrent chains procedure.

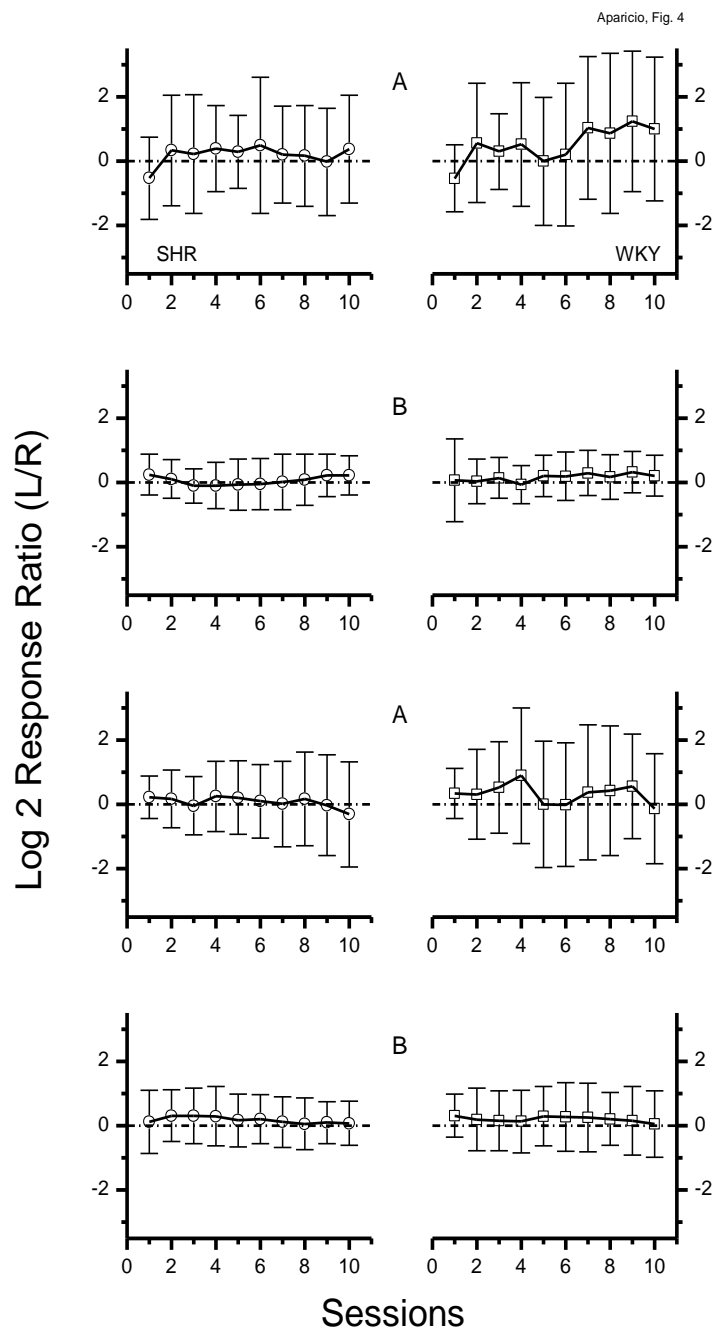


Statistical analyses (via Paired Sample t Test) showed that in condition *B* the responses that the SHRs emitted on the left-lever were significantly higher [$t(9) = 4.59, p = 0.001$] than those emitted in condition *A* and its redetermination [$t(9) = 2.21, p = 0.027$]; also the number of responses in the redetermination to condition *B* was significantly higher [$t(9) = 9.69, p = 0.000$] than those in the redetermination to condition *A*. Accordingly, the number of responses that the WKYs emitted in condition *B* on the left-lever was significantly higher [$t(9) = 5.04, p = 0.000$] than the number of responses emitted on that lever in condition *A* and its redetermination [$t(9) = 3.09, p = 0.007$]; the redetermination to condition *B* also showed a significantly higher number of responses on the left-lever [$t(9) = 9.80, p = 0.000$] than those in the redetermination to condition *A*.

Further statistical analyses showed that in condition *B*, the number of responses that the SHRs emitted on the right-lever was significantly higher [$t(9) = 4.69, p = 0.001$] than those emitted in condition *A* and the redetermination to that condition [$t(9) = 3.10, p = 0.007$]; the redetermination to condition *B*

revealed that responses on the right-lever were significantly higher [$t(9) = 9.80, p = 0.000$] than the number of responses emitted on that lever in the redetermination to condition *A*. Consistently, the WKYs in condition *B* emitted a significantly higher number of responses on the right-lever [$t(9) = 4.75, p = 0.001$] than those emitted on the same lever in condition *A* and its redetermination [$t(9) = 3.53, p = 0.003$]; lastly, the number of responses that the WKYs emitted on the right-lever in the redetermination to condition *B* was significantly higher [$t(9) = 9.00, p = 0.000$] than those they emitted in the redetermination to condition *A*.

Figure 4. Log 2 of response ratios (L/R) generated by the SHRs (circles) and WKYs (squares) against number of session of the concurrent chains procedure. Other details as in Figure 3.



Additional statistical analyses showed that condition *A* was the only condition where the number of responses emitted on the left-lever was significantly different between strains [$t(9) = 4.12, p = 0.003$].

The last analysis assessed the possibility of a systematic bias for either the left- or the right-lever that SHRs (circles) and WKYs (squares) might have developed during the concurrent-chains procedure. The ratio (left-/right-lever) of groups' average responses was plotted in Figure 4 against the number of sessions arranged for conditions *A* and *B* and their redeterminations (note log base 2 scale on the y-axis). Condition *A* (top row) is the only condition that shows a slight bias for responding on the left-lever. For condition *B* and redeterminations to conditions *A* and *B*, Figure 4 shows that the data points for both the SHR and WKY fall on the indifference line. Statistical analyses revealed that the redetermination to condition *A* was the only condition where the ratios of responses were significantly different between strains [$t(9) = 2.79, p = 0.0105$] across sessions. The data of the individual SHR and WKY rats were consistent with the corresponding groups' average data. Figure A2 in Appendix-A shows the log 2 of response ratios computed from the individuals across condition *A* and *B* and their redeterminations.

Discussion

Response Acquisition in Positive Automaintenance

In the present study strain differences in lever-pressing acquisition were observed between SHR and WKY rats responding under a positive automaintenance procedure (Williams and Williams, 1969). When compared to the SHRs, WKY rats exhibited retarded acquisition of lever pressing and emitted fewer responses on the left and right levers in 10 out of 30 sessions of the positive automaintenance procedure. This result was in opposite direction to that obtained in previous studies where the SHRs and WKYs were exposed to a tandem FR1 DRO 15-s schedule of reinforcement, where one lever-press initiated either a 15-s unsignaled delay (i.e., Hand, Fox, & Reilly, 2006) or a 15-s signaled delay to reinforcement (i.e., Hand, Fox, & Reilly, 2010) with responses during the DRO resetting the delay. With the 15-s unsignaled delay to reinforcement response acquisition was retarded in the SHRs (Hand et al., 2006), but no differences in response acquisition were found between strains when the tandem FR1 DRO 15-s signaled the delay to reinforcement with the illumination of the houselight (Hand et al., 2010); the SHRs and WKYs emitted similar numbers of responses, with comparable delay resets and food-pellets earned. The discrepancy in findings between the former and the latter study was explained by Hand et al. (2010) arguing that the SHRs are more sensible to the effect of unsignaled delay; consequently, signaling the delay to reinforcement nullified strain differences in lever-pressing acquisition between the SHRs and WKYs. Such possibility is supported by research showing that signaled delay to reinforcement facilitates operant responding in steady state (e.g., Lattal, 1984; Reilly & Lattal, 2004; Richards, 1981; Schaal & Branch, 1988, 1990) and acquisition procedures (e.g., Critchfield & Lattal, 1993).

The hypothesis that lack of attention is the mechanism accounting for the retarded lever-pressing acquisition in SHR rats was not supported by the present results showing that the SHR rats acquired lever-pressing faster than the WKY rats, suggesting that impulsive action or motor impulsivity is the mechanism accounting for sign-tracking behaviors (Tomie, Grimes, & Pohorecky, 2008). Alternatively, the present results support the notion that rats tracking signals show impulsive action (Flagel, Robinson, Clark, Clinton, Watson, Seeman, Phillips, & Akil, 2010; Lovic, Saunders, Yager, & Robinson, 2011) and/or reduced inhibitory control (Tomie, Grimes, & Pohorecky, 2008), and it can be used to predict autoshaping of lever-pressing (Tomie, Aguado, Pohorecky, & Benjamin (1998).

Our results, however, showed that after 11 sessions of positive automaintenance, the WKY rats began responding consistently on the left and right levers and continued responding for the next 19

sessions, reaching levels of cumulative responses that were of similar numbers to those the SHR rats reached in comparable sessions. This finding resembles that obtained with LEW and F344 rats in choice situations where differences in impulsivity between strains in initial training vanished with extended training, showing that with experience in the concurrent-chains procedure both strains perform at comparable levels across conditions (Aparicio, Hughes, & Pitts, 2013).

Nonetheless, in the present study the SHR rats emitted more responses on the rear lever than those the WKY rats emitted on that lever across 30 sessions of positive automaintenance. Recall that the rear lever was permanently available in the operant chamber with no scheduled consequences. Henceforth, any response on the rear lever might be considered a food-induced activity resulting from a potential contingency between food delivery and responses occurring approximately at the end of the 15-s presentation of either the left or right lever (for theoretical review, see Baum & Davison, 2014). It has been shown that in some conditions food-induced activities interfere with operant activities, as it was the case for lever pressing in Breland and Breland's (1961) study; however, these authors also reported that food-induced activities might facilitate training, as it occurred for key pecking in autoshaping studies (Brown & Jenkins, 1968, Hearts & Jenkins, 1974) and lever pressing in the present positive automaintenance (Williams & Williams, 1969) procedure. Overall, the results of the present study agree with the notion that food induced activities are related to phylogenetically important events (PIEs) by phylogenetic (genetic endowment) and ontogenetic (life time of conditioning) histories (Baum, 2005, 2012).

Response maintenance in Concurrent chains

A concurrent-chains procedure was used to examine possible between strain differences in total responses that can be attributed to different levels of hyperactivity. Because the SHRs are more active (i.e., show impulsive action or motor impulsivity) than the WKYs, the former strain was expected to produce more responses than the latter strain when responding to RT and RI schedules arranging entries to terminal links. A second objective was to determine whether the SHRs and WKYs could differentiate between RT and RI schedules by responding at low response rates to the former and at high response rates to latter schedule. For this purpose, response-independent and response-dependent terminal links entries were manipulated according to a reversal ABAB experimental design. The idea was to identify plausible between strain differences in total responses that can be attributed to different levels of impulsivity. If the SHRs press on the levers more impulsively than the WKY rats, then it was expected that the SHRs would respond to a higher response rate across conditions, regardless of whether the schedule arranging entries to the terminal link was a RT or a RI schedule. Another possibility is that between strain differences in responding occur early in training, and disappear with extended experience in the concurrent chains schedule, as it was shown in previous studies with LEW and F344 rat strains (Aparicio, Hughes, & Pitts, 2013). Accordingly, the SHR and WKY rats would perform at comparable levels across conditions, responding at low rates to the RT schedule and at high rates to the RI schedule, and there would be no differences between strains with extended training in the present concurrent-chains procedure.

Results show that condition *A* was the only condition where the SHR rats emitted more responses than the WKYs on the left lever, and that difference was significant [$t(9) = 4.12, p = 0.003$]; however, in the same condition *A* there were no between strain differences on the number of responses emitted on the right lever. Also, in condition *B* and redeterminations to conditions *A* and *B*, the SHRs and WKYs emitted a comparable number of responses on the left and right levers concurrently available in the initial link, ruling out the hypothesis that SHRs will produce more responses than the WKYs when

responding to both RT and RI schedules arranging entries to the terminal links of a concurrent-chains procedure.

Furthermore, the present results showed that both strains discriminated between RT and RI schedules, responding at low response rates to the former and at high response rates to latter schedule concurrently available in the initial link of the concurrent-chains procedure. In all cases, the total number of responses that the SHRs and WKY rats emitted on the left and right lever in conditions *B* and its redetermination, was significantly higher than the total number of responses that both rat strains emitted on the left and right levers in condition *A* and its redetermination. Thus, the hypothesis that the SHR rats will respond to the levers at a higher response rate across conditions, regardless of whether the schedule arranging entries to the terminal link was a RT or a RI, was not supported by the results of the present study. Instead, the notion that between strains differences in response acquisition occur early in training, but disappear with extended training, as it was shown in previous studies with LEW and F344 rats (Aparicio, Hughes, & Pitts, 2013), was supported by the present results, showing that the SHR and WKY rats responded to comparable response rates across conditions of an ABAB reversal experimental design where entries to the terminal links were manipulated across conditions using RT and RI schedules of reinforcement.

The last analysis of the data assessed the possibility of a systematic bias for either the left- or the right-lever that the SHRs (circles) and WKYs (squares) might have been developed either during the acquisition of lever pressing in the positive automaintenance procedure or when responding to the concurrent-chains procedure. It was important for our current research program aimed to examine potential initial differences in impulsivity between SHR and WKY rats; a baseline showing no systematic bias for either the left- or the right-lever can be used for further research manipulating the amount of food and the delay to food delivery in the terminal links of the concurrent chains-procedure. (As it is the case of the present research protocol that in phase II is currently assessing preference for a larger-later reinforcer over a smaller-sooner reinforcer).

Our results showed that condition *A* was the only condition where the SHR and WKY rats exhibited a slight bias for responding on the left-lever; in condition *B* and redeterminations to conditions *A* and *B*, the SHRs and WKYs generated data points indicating indifference for responding either on the left- or the right-lever. Moreover, the redetermination to condition *A* was the only condition where the ratios of responses generated by the SHRs were significantly different from those produced by the WKYs [$t(9) = 2.79, p = 0.0105$].

Conclusions

The present results show retarded acquisition of lever pressing in WKY rats as compared with SHR rats. The hypothesis that lack of attention is the mechanism accounting for the retarded lever-pressing acquisition in SHR rats was not supported by the present results, suggesting that impulsive action or motor impulsivity is the mechanism accounting for sign-tracking behaviors, lever-pressing in the present study. The notion that rats tracking signals show impulsive action (Flagel, Robinson, Clark, Clinton, Watson, Seeman, Phillips, & Akil, 2010; Lovic, Saunders, Yager, & Robinson, 2011) and/or reduced inhibitory control (Tomie, Grimes, & Pohorecky, 2008), was supported by the present results showing that impulsive action facilitated the autoshaping of lever-pressing in SHR and WKY rats. Early in training, however, the former strain emitted fewer responses than the latter strain on the left and right levers. Later in training, there were no between strain differences in responding to the left and right levers; the WKY rats reached cumulative numbers of responses that were similar to those the SHR rats reached in comparable sessions of positive automaintenance. The present results agree with the notion that food

induced activities are related to phylogenetically important events (PIEs) by phylogenetic (genetic endowment) and ontogenetic (life time of conditioning) histories (Baum, 2005, 2012). The concurrent-chains procedure showed no differences between strains in response maintenance; the SHRs and WKYs emitted a comparable number of responses on the left and right levers concurrently available in the initial link, ruling out the idea that SHRs will produce more responses than the WKYs when responding to both RT and RI schedules arranging entries to the terminal links of a concurrent-chains procedure. This finding is consistent with that obtained with LEW and F344 rats using a similar concurrent-chains procedure, showing that between strains initial differences in impulsivity disappear with extended training in a concurrent-chains procedure (Aparicio, Hughes, & Pitts, 2013). The SHR and WKY rats responded at low rates to the RT schedule and at high rates to the RI schedule, indicating that both strains established discrimination between response independent and response dependent schedules, respectively. Lastly, the results showed no systematic bias for responding either on the left- of the right-lever, the SHRs and WKYs generated response ratios indicating indifference. The results of the present study could be used as a baseline for further research assessing the effects of varying the amount and delay to reinforcement in the impulsive choices of SHR and WKY rats.

Appendix-A

Figure A1. Response rates (minutes) computed for the individual SHR (left column) and WKY rats (right column) against number of session of the concurrent chains procedure. Heavy lines stand for computations on left lever and short-dot lines computations on the right lever across conditions (ABAB) of the concurrent-chains procedure.

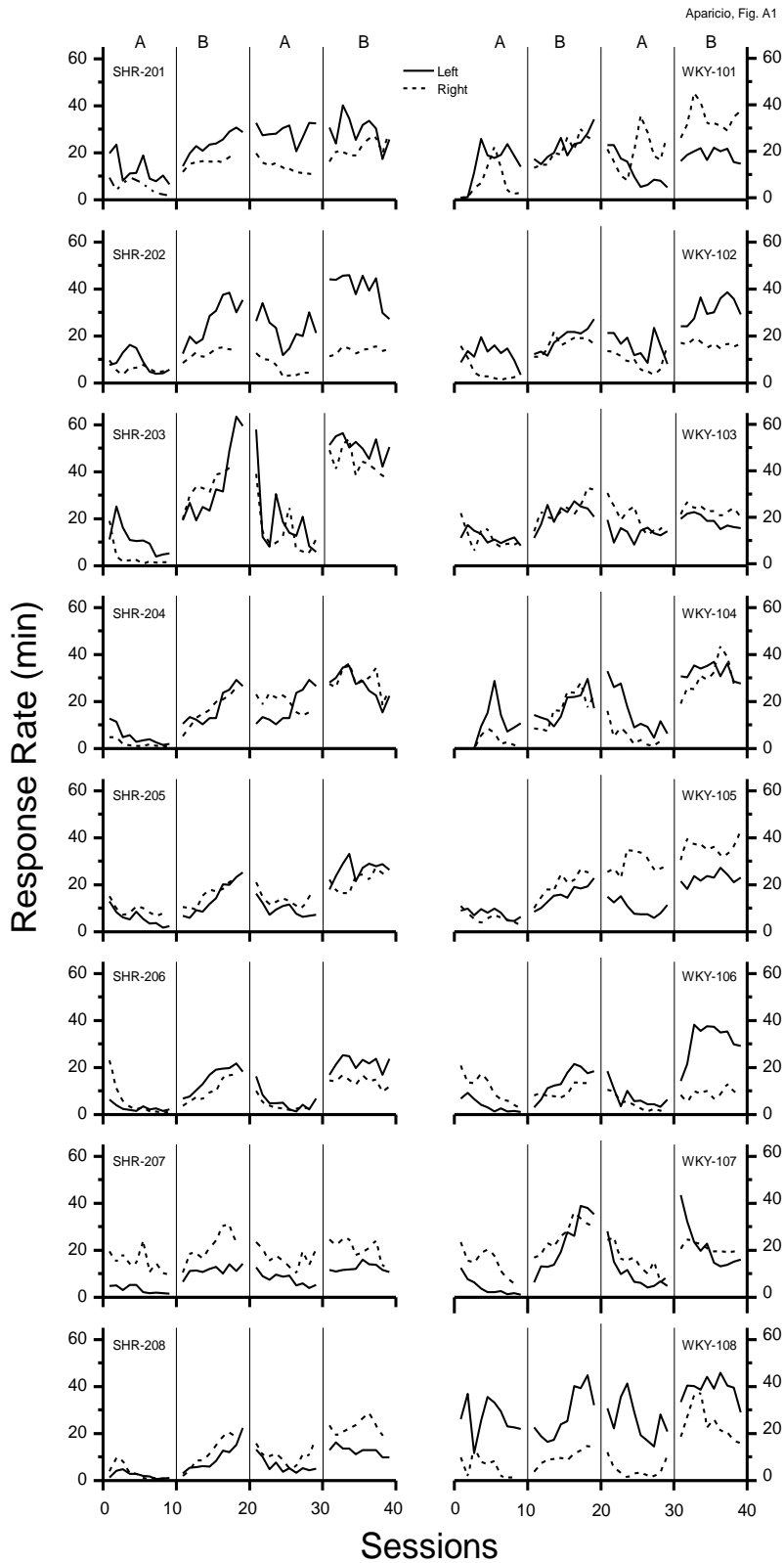
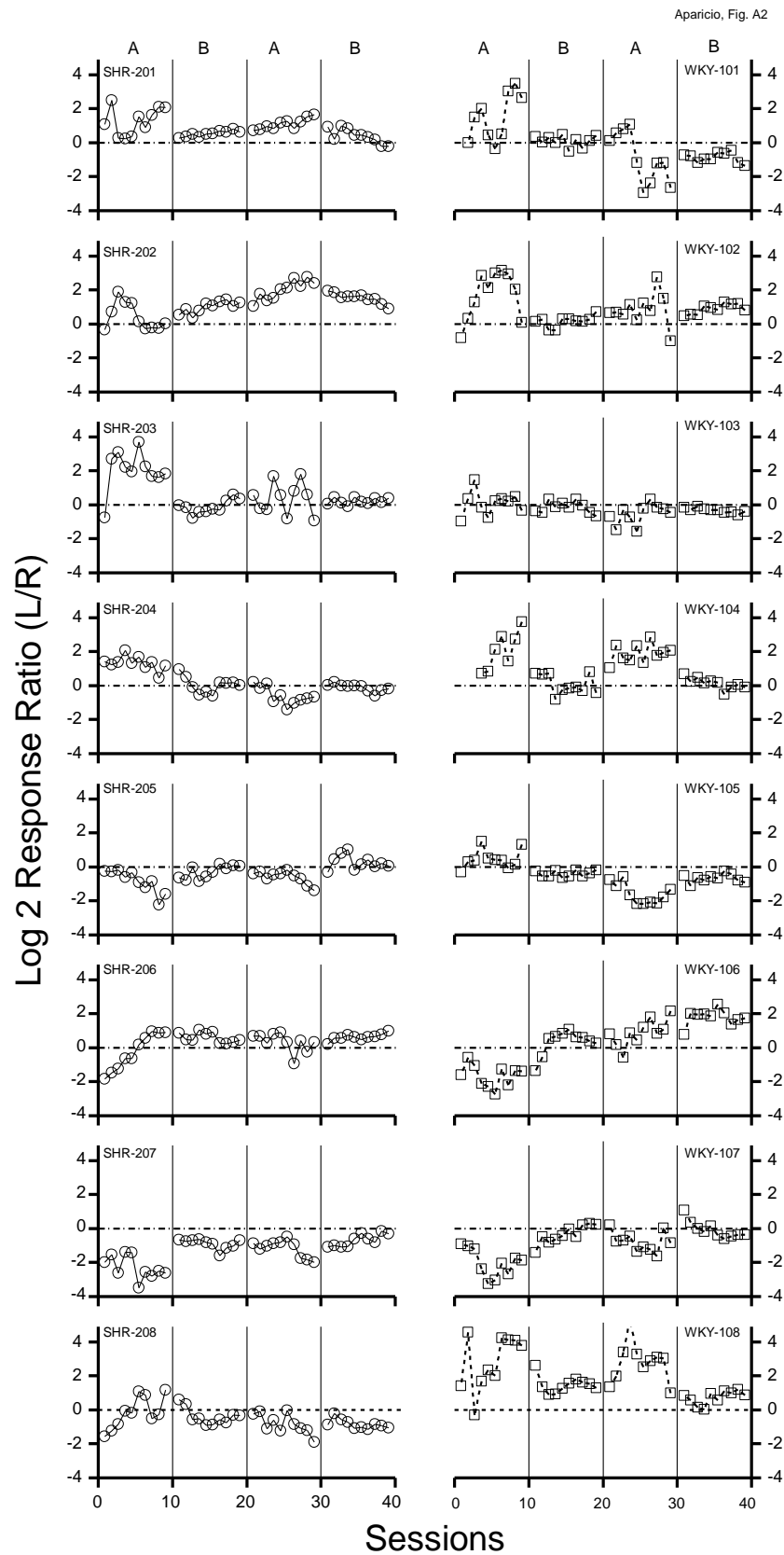


Figure A2. Log 2 of response ratios (L/R) generated by the individual SHR (circles) and WKY rats (squares) against number of session of the concurrent chains procedure. Other details as in Figure A1.



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