

Effects of Environmental Enrichment and Corticosteroid Levels on Cognitive Control in *Mastomys Natalensis* Rats

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ABSTRACT This study examined the efficacy of environmental enrichment and corticosteroid levels in influencing cognitive control in *Mastomys Natalensis* rats. Primarily this paper assessed whether enhanced environmental conditions could influence the adverse effects of elevated corticosteroid levels on cognitive functions, particularly cognitive control associated with decision-making and impulse control. The subjects for this study were a sample of thirty (30) older adult *Mastomys Natalensis* rats. They were randomly selected and randomly selected to the three groups for the study, namely the Environmental Enrichment Group; the Exercise group; and the Control group. The instrument used in this experiment for the measurement of cognitive controlling is the Hebbian Maze Box (the Complex Maze). Results indicated that rats in enriched environments exhibited significantly lower corticosteroid levels compared to their counterparts in standard conditions. These rats demonstrated improved performance on cognitive tasks requiring higher-order thinking and problem-solving abilities. The findings suggest that environmental enrichment not only reduces stress-related hormonal responses but also enhances cognitive resilience against the detrimental effects of stress. Conversely, no significant difference of corticosterone was found on the groups. No significant interaction was observed between environmental enrichment and corticosterone levels on executive function. This research underscores the importance of environmental factors in shaping cognitive health and offers insights into potential interventions for influencing stress-related cognitive impairments in mammals. Future studies should explore the underlying mechanisms by which environmental enrichment influences neuroendocrine responses and cognitive function. It is recommended that meta-analytic studies should be conducted to further provide evidence for future studies.

KEYWORDS: Environmental Enrichment, Corticosteroid, Cognitive Control, *Mastomys Natalensis* Rats

I. INTRODUCTION

One of the primary concerns of environmental enrichment is to bring caged animals in proximity to their natural behaviors. This includes activities like climbing, digging, gathering food, and socializing. Environmental enrichment in rats help foster animal activity that brings out species-specific positive behavior, and improve the animals' general health [1]. Social housing and nesting/hiding materials are two aspects of mice's environmental enrichment [2]. Environmental enrichment is crucial for improving the overall welfare of captive animals [3]. In natural habitats, animals engage in a variety of behaviors necessary for their survival, such as foraging, exploring, and socializing. Captive environments often lack the complexity and stimulation found in the wild, which can lead to boredom, stress, and the development of abnormal behaviors known as stereotypies [6]. By introducing enrichment that mimics natural conditions, animals can express species-specific behaviors that contribute to their mental and physical well-being [4]. Prenatal malnutrition can change the development of the Central Nervous System (CNS), especially hippocampus plasticity, according to studies conducted on rats [5]. The CA1 area of the hippocampus may not develop as well as it should due to changes in neuro-genesis and CNS development shown in early starved rats [5,7,8]. Malnutrition may change the Control of Corticosterone (CORT) negative feedback in the Hypothalamic/Pituitary/Adrenal (HPA) axis and decrease the expression of Corticosteroid Receptors (CR) in the brain, especially in the hippocampus [8; 9; 10; 11]. These results highlight the effects of early malnutrition on HPA axis activity [12,13]. Some authors [9,11,14,15] have demonstrated that undernourished rats show behavioral changes, including increase in the degree of entry and times spent in the open arms in the elevated Plus Maze-Test (EPM) as well as, differences in head plummeting and distending behavior [9,16,17], which indicate an altered anxiety response [15,18]. Decline in processing speed, memory, and cognitive control is a relatively widespread characteristic of aging [18; 19].

Cortisol is a Corticosteroid hormone that your adrenal glands produce and release [20]. According to [9] hormones are chemicals that coordinate different functions in your body by carrying messages through your blood to your organs, skin, muscles and other tissues. These signals tell your body what to do and when to do it. Corticosteroids are a type of steroid hormone and they suppress inflammation in all of your bodily tissues and control metabolism in your muscles, fat, liver and bones [21,22]. Cognitive control is a set of mental skills that include working memory, flexible thinking, and self-control. These skills involve daily skills required to carry out day-to-day routines and manage daily activities. Trouble with cognitive control can make it hard to focus, follows directions and handle emotions among other things [19]. The cognitive controls are a set of processes that all have to do with managing oneself and one's resources in order to achieve a goal. The term cognitive controls refer to the higher-level cognitive skills used to control and coordinate other cognitive abilities [23]. Chronic stress (long-term) stress happens when you experience ongoing situations that cause frustration or anxiety [24]. For example, experiencing an extreme weather event can lead to Post-Traumatic Stress Disorder (PTSD). Body releases cortisol when you experience any of these types of stress [25]. Exercise may be an effective approach to preserve and improve cognitive function and brain health in late adulthood. For example, randomized clinical trials have found that moderate-intensity exercise improves memory and cognitive control [24], increases prefrontal cortex [15;26] and hippocampal volumes [25], and influences brain network connectivity. Epidemiological studies have supported these results and demonstrate that higher fitness levels and greater amounts of physical activity are associated with greater gray matter volumes [26], white matter integrity reduced brain atrophy rates and reduced risk of cognitive impairment and dementia. Yet, the mechanisms by which exercise improves or maintains brain health in humans remain poorly understood, but likely include changes in inflammation, insulin resistance, as well as central changes in serotonin, dopamine, or other neurotransmitters [12]. This suggests that cortisol plays a significant role in the initiation of wakefulness

and plays a part in your body's circadian rhythm [27]. Optimum cortisol levels are necessary for life and for maintaining several bodily functions. If you have consistently high or low cortisol levels, it can have negative impacts on your overall health [28]. Adrenocorticotrophic Hormone (ACTH) then stimulates your adrenal glands to produce and release cortisol [29]. In order to have optimal levels of cortisol, the hypothalamus, pituitary gland and adrenal glands must all be optimally functional in rats [24]. However, recent studies have shown that rats kept in an enriched environment differ from those kept in standard cages in dendritic branching, synaptogenesis, memory function, emotionality and behaviour [30,31].

This study examines whether environmental enrichment and corticosteroid levels influence cognitive control in *Mastomys natalensis*, addressing gaps in our understanding of stress-related cognitive impairments within the field of behavioral neuroscience. Despite the support from scientific literature that demonstrates that cognitive processes (working memory, flexible thinking, and self-control), are essential for adaptive behavior, only a handful of studies have reported consistent findings to support this supposition. The paucity of demonstrable laboratory studies have informed the rationale for conducting this study. This study aims to explore whether environmental enrichment through visual and auditory stimuli can counteract the negative effects of elevated cortisol level on cognitive controlling in this rodent model. If this type of study is not conducted, several significant implications for scientific research may significant implications. Given the advancement in clinical treatment, more information and knowledge regarding the interplay between environmental factors and stress responses could foster advancements in the improvement of neuropsychological treatments for stress-related cognitive impairments. The need for empirical studies, necessitates that researchers develop insights into critical areas to solve problems relating to the roles of environmental enrichment for enhancing cognitive resilience against stressors. Also, overlooking this type of research could extend gaps in knowledge concerning species-specific responses to stress and enrichment strategies, limiting the applicability of findings across different models. Failing to examine these associations may stall advancement in developing operative mediations aimed at improving cognitive health in both animal models and possibly human populations facing comparable challenges.

II. LITERATURE REVIEW

The main paradigm for analyzing physical activity has been the social cognitive tradition, which has offered useful information on key constructs associated with physical exercise [49]. Social Cognitive Theory (SCT) represents a parsimonious model to understand physical activity [50]. Most research that has used SCT has focused on the self-efficacy construct. Some important critiques of SCT have emerged in recent years. SCT has left a considerable legacy on the field of sport and exercise psychology. Barkley, one of the leading experts in the fields of attention deficit hyperactivity disorder and cognitive controlling, describes how cognitive controls allow for self-regulation [50]. Barkley describes how cognitive controls help control human behavior, ranging from that which involves external events to mental representations of those events; control by others to control of the self; immediate reinforcement to delayed gratification; and the present to the possible future. Barkley posits that the ability to "inhibit a preponderant response" is the primary cognitive control upon which other functions evolve. Modern definitions of cognitive controls emphasize the role of human experience and the environment [51]. These perspectives regard the brain-basis of cognitive controls as flexible in response to teaching, practice, and learning opportunities. This concept, confirmed by recent neuroscience research, is congruent with the Learning-Works for Kids paradigm, which sees cognitive "skills" as capacity to participate in purposeful activity rather than fixed talents in the brain [52;53].

EXERCISE AND COGNITIVE FUNCTIONING

The relationship between exercising and cognitive performance has been demonstrated in multiple domains of experimental research. In a meta-analysis of 15 observational studies investigating the association between exercise and cognitive function in older adults in rodents, [32] found a significantly reduced risk of

cognitive decline for participants engaged in exercise. Across the 15 studies 33, 816 non-demented subjects (Mean ages > 55) were observed over a 1–12-year period, and assessments of were obtained through self-report or questionnaires and cognitive performance was examined predominately through the Mini-Mental State Exam (MMSE). The authors found that even modest levels of exercise can have beneficial effects on cognition with the meta-analysis revealing a 38% reduced risk of cognitive decline for participants with a high level of exercise compared to sedentary participants and, similarly, a 35% for participants performing low to moderate levels of exercising [32]. Clinical intervention research has also extensively assessed the association between level of exercise and cognitive outcomes. One meta-analysis looked at eighteen intervention studies examining the effect of fitness training on the cognitive performance of healthy but sedentary older adults [33]. They found that, compared to controls, exercisers showed significantly improved results of moderate effect size in the cognitive domains of cognitive control, cognitive control, visuospatial processing and a significant increase of small effect for reaction time [33]. In another review of epidemiological studies that examined modifiable factors associated with cognitive decline and dementia, 24 studies linking PA to cognitive outcomes were assessed and of these 21 (87.5%) found a positive relationship between exercising and cognitive performance [11]. Animal studies have also demonstrated the benefits of physical activities (PA) on cognitive function, such as; better long-term and short-term memory in rats exposed to a swimming regime compared to non-exercised controls [34;35]; improved object recognition memory for rats assigned to a rodent treadmill, running condition compared to rats in sedentary condition [36]; and female Cynomolgus monkeys, taught to run on treadmills for an hour a day, were significantly faster at learning the Wisconsin General Test Apparatus (WGTA; designed to test learning in primates) than controls [37]. In addition, animal studies have enabled the research, through more invasive procedures than are possible with human subjects, to reveal the cellular and molecular mechanisms that occur with increased physical activity that impact the neurological structure of cognition [38].

ENVIRONMENTAL ENRICHMENT AND COGNITIVE CONTROLLING

Rats were exposed to Environmental Enrichment (EE) consisted of a transparent plastic cage (40x25x20 cm) which contained activity wheels, tunnels, plastic toys (with different shapes and textures), marbles, objects that emitted sounds (e.g., rattles), mirrors and pieces of wood. Each litter that was assigned to the group was placed in the enriched environment, without their mothers, for 1 hour per day; litters were then returned to their mothers in the irrespective home cages. The groups not exposed to an enriched environment during the lactation period were kept in a home cage, but separated from their mothers during the same period of time expended manipulating the stimulated groups. Connected with ramps, containing an activity wheel, plastic toys, rubber balls, wooden objects with different shapes, textures and colors, objects that could emit sound when touched by the animals, and mirrors on the lateral walls, was used for the enrichment protocol [9,29], 7 to 10 rats from different groups were placed in the apparatus at a time. After which each rat was returned to its home cage. EE objects were changed weekly to guarantee novelty effect [9, 39,40].

Some studies in rats indicate that malnutrition during the prenatal period can alter development of the Central Nervous System (CNS), particularly hippocampal plasticity [5,8,41]. Alterations in neurogenesis and CNS development, observed in early mal-nourished rats [5,8] may result in deficits in development of the CA1 region of the hippocampus [5] reductions in total dendritic ramification [42,43] and number of synaptic spines [44,45]. Early malnutrition may also lead to a reduction in Corticosteroid Receptor (CR) expression in the brain, particularly in the hippocampus, and possibly alter regulation of Corticosterone (CORT) negative feedback in the Hypothalamic–Pituitary–Adrenal (HPA) axis [9,11]. Primary malnutrition has been shown to increase Adrenocorticotrophic Hormone release and free CORT levels [8,11] which are associated with low levels of brain-derived neurotrophic factor [12]. These results highlight the effects of early malnutrition on HPA axis activity. Early malnourished rats show behavioral changes, including higher numbers of entry and time spent in the open arms in the elevated Plus Maze-Test (EPM)

[12,15] as well as differences in head dipping and stretching behavior [9,26,46,47], which indicate an altered anxiety response. This altered behavior is associated with failures in risk assessment, as animals demonstrate greater impulsivity when faced with a new situation, and impairments in anxiety response [9,48]. Anxiety-related behavioral changes following protein malnutrition have also been observed in other animal tests of anxiety, such as the elevated T-maze [15,18].

III. METHODOLOGY

PARTICIPANTS

The subjects for this study were a sample of thirty (30) older adult *Mastomys Natalensis* rats. They were randomly selected to the three groups for the study, namely the Environmental Enrichment Group, the Exercise group and the Control group. The subjects were assigned as eighteen males and twelve females, six males and four females in each group. Each of the three groups had three cages, two cages for the male rats and one cage for the female rat, making the total of nine cages. Then each of the male cages housed three rats while the female cages housed four rats.

RESEARCH QUESTIONS

The present study would be interested in answering the following questions:

- (a). Does exercise affect cognitive control (performance on Hebbian Maze) in *Mastomys Natalensis* rats?
- (b). How does cortisol level influence cognitive performance in *Mastomys Natalensis* rats?
- (c). Would there be an interaction effects of exercise and cortisol on Hebbian Maze performance in *Mastomys Natalensis* rats?

RESEARCH HYPOTHESES

Based on the research questions, the following hypotheses were formulated:

- (a). *Mastomys Natalensis* rats exposed to environmental enrichment will demonstrate significantly better cognitive control than non-exposed rats.
- (b). Cortisol level will lead to improvement in Hebbian Maze performance in *Mastomys Natalensis* rats, as compared to *Mastomys Natalensis* rats with low cortisol levels.
- (c). There would be significant joint interaction effect of exercise and cortisol on Hebbian Maze performance in *Mastomys Natalensis* rats.

INSTRUMENTS

The instrument used in this experiment for the measurement of cognitive controlling is the Hebbian Maze Box (the Complex Maze). The Hebbian Maze was used to assess cognitive performance by tracking spatial learning, memory retention, and problem-solving abilities in rats.

PROCEDURES

Firstly, the rats were randomly selected using the balloting method (each rat was numbered in odd and even numbers and those with odd numbers were selected) and assigned to the environmental enrichment, exercise and control groups respectively. In order to determine the effect of corticosteroid levels on cognitive control, the experiment measured both the rate of error and time each rat in the different assigned group where able to complete the Hebbian Maze. The rats were matched based on sex and each group had six male rats and four female rats a total number of ten rats in each group. Each group had a total of three cages, that is two cages for the male rats and one cage for the female rat, three rats per cage. The rats were kept for two weeks to be acclimatized with the environment. They were kept in the condition of twenty-

four hours' light and twenty-four hours' darkness with water and food provided morning and evening. After the total two-weeks of acclimatization, the rats were then exposed to their laboratory environment in routine order for the manipulation of the Environmental Enrichments and Exercise groups and the control of the control group.

The environmental enrichment groups were brought to the laboratory on Tuesdays and Fridays while the Exercise and Control groups were brought to the laboratory on Wednesdays and Saturdays. The environmental enrichments used for the rats were flashing light, musical tunes and figurines in an enclosed and dark laboratory room. The exercise group were made to play with the running wheel, the lever/see-saw and the pipes to run through in day light without musical tunes. While the control groups were just taken out of their natural habitat and kept in the laboratory environment without food or water. The intervention process was such that the rats in the environmental group were kept in the box of different figurines, the flashing light was put on and musical tunes was played for them. They were put into the box one cage at a time, that is three rats at a time as earlier explained. Each set of rats were left to play with the figurines for thirty minutes.

With regards to the exercise group the process was quite different as there were two boxes for the exercise group. One had the pipes and the other had the running wheel and the lever/see-saw. One group of rats was placed in the box with pipes, while another group was placed in the box containing the running wheel and the lever/see-saw. Each of the groups were allowed to roam around and get involved for fifteen minutes each then the rats were being switched. Those in the box with pipes were put into the box with the running wheel while those in the box containing running was taken to the box with pipes. The rats were left again for a period of fifteen minutes, making a total of thirty minutes. After this the last group was put and left for the same period of time as the other two groups (cages). The intervention process lasted for a period of two months and then the rats were left to rest for one week. After the one-week rest, the rats were then brought to the laboratory to test their Spatial learning and Spatial memory using the Hebbian Maze box, the Complex maze box. Before this process began, the rats were being marked with permanent marker to enable me know which rat is undergoing the treatment at a given time because it's hard to know which rat is which since they were mixed in the same cage according to the groups. In this process then, bait (food) was placed in the maze box at the end of it with signs around the walls as a guide on how to get there. Then the rats were being placed inside the box through the entrance of the maze box and timed to get the record of how long it took them to get to the food.

Each rat was given three trials and each trial was set for 300 seconds. As the rat is being placed in the entrance the timer starts and once the rat gets to the food and eats it the timer stops and the time is recorded. In cases where the rat is not able to locate the food before the 300 seconds run out the rat is being taken to the position where the food is to enable it know where the food is then it is removed and put back for the testing of spatial learning. At the end of the third trial the faecal of the rats in the box is being recorded as the "faecal count". The faecal count is to help measure the level of anxiety in the rat at that point in time. In addition, it is necessary to know that before any measurement or test the rats were not given food or water in order to make them hungry and motivated to search for the food. This process lasted for a four-day period, then the rats were given a four-days break, to enable the efficiency of the spatial memory test, here they were being fed in the morning and evening. After the four days' break, the rats were then brought back to the laboratory to test their spatial memory. At this point, each rat was given the chance to undergo the test in one trial only for 5 minutes each. The same process was repeated again as the one for the spatial learning. This was to know how much they remember from what they learned in those four days. After each trial faecal count was done and recorded. Instruments like vials, chlorpromazine injection, benzodiazepine, centrifuge tubes with caps, dextrose sensa line, surgical tools and hand gloves. The centrifuge tubes were then labelled with the colour, gender and group of each rat for the placement of the hair cortisol and the brains. Those that would contain the brains were filled half way with formalin, while those that would contain the cortisol were left empty. This procedure began with the environmental enrichment group males, since the rats' bodies were already marked with different colours of markers it was easy to identify each rat

for the correct placement of each cortisol extracted. One and half ampules of Diazepine and one and half ampules of Chlorpromazine was injected into the rats, the hair samples were taken from the end of spine close to the tail. The rats were left to sedate then were opened from the abdomen. The cuts were wide enough that it reached the thorax. Then when the heart came into sight one-third of the Dextrose Sen Saline drip was then injected into the heart to the brain so as to make the blood in the brain diffuse leaving the brain white and then formalin was being introduced into the heart also to the brain to make the brain hard so that when it is being extracted from the skull it would not break apart. The formalin was left to get to the brain then the head of the rat was cut off and the brain extracted from the skull and placed into a centrifuge tube which contained formalin. The brains and cortisol are presently in the laboratory ready to be taken to the laboratory for further analyses.

DESIGN AND STATISTICS

The design of the study was a Randomized between group experimental design. Two-way analysis of variance was used for data analysis. The two way was computed using the SPSS version 25. MANOVA was chosen to assess differences across multiple dependent variables simultaneously, accounting for their correlations and enhancing statistical power.

IV. RESULTS AND DISCUSSION

Table 1: Summary Table of MANOVA of Environmental Enrichment on Cognitive Control

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Day1	284958.271 ^a	5	50345.740	1.535	.267
	Day2	311245.583 ^b	5	61045.254	.782	.376
	Day3	208778.104 ^c	5	35724.441	.674	.377
	Day4	137312.771 ^d	5	27462.554	.342	.854
	Total trial	218199.271 ^e	5	444529.854	.916	.509
Intercept	Day1	4882911.736	1	405333.543	101.322	.000
	Day2	4530549.563	1	594231.770	94.348	.000
	Day3	6775515.414	1	893352.414	253.033	.000
	Day4	8626276.149	1	7758446.224	576.104	.000
	Total trial	1006856.149	1	1068562.149	329.423	.000
Group	Day1	205553.735	2	133064.674	2.662	.132
	Day2	182708.760	2	96435.380	1.291	.155
	Day3	112436.842	2	56218.421	1.446	.306
	Day4	114916.078	2	35938.039	3.837	.058
	Total trial	1665979.432	2	667029.705	1.687	.234
Cortgroup	Day1	32480.011	1	32480.011	.876	.371
	Day2	138880.184	1	138880.184	2.118	.176
	Day3	67370.586	1	67370.586	1.601	.234
	Day4	986.770	1	986.770	.066	.803
	Totaltrial	767416.563	1	767416.563	1.667	.226
Group * Cortgroup	Day1	41430.406	2	20715.203	.559	.589
	Day2	7673.023	2	3836.512	.059	.943
	Day3	61711.703	2	30855.852	.733	.504

Error	Day4	22932.019	2	11466.010	.766	.490
	Totaltrial	1294.009	2	647.004	.001	.999
	Day1	370697.667	10	37069.767		
	Day2	655696.167	10	65569.617		
	Day3	420719.333	10	42071.933		
	Day4	149734.667	10	14973.467		
	Total Trial	4603451.167	10	460345.117		
Total	Day1	6186139.000	16			
	Day2	6859698.000	16			
	Day3	8476499.000	16			
	Day4	9889299.000	16			
	Total Trial	120277971.000	16			

Table 2 shows significance for Day 1 with a p-value of 0.267, indicating no significant effect at this time point. For Days 2, 3, and 4, p-values are 0.376, 0.377, and 0.854 respectively; all indicate no significant effects across these days. With regards to the Intercept, all days show highly significant results ($p < 0.001$), suggesting that there are strong overall effects present across all days when considering the intercept. Also, Group Day 1 shows a marginally significant result ($p = 0.132$), while Days 2 and 3 do not show significance ($p = 0.155$ and $p = 0.306$ respectively). On Day 4, the environmental enrichment group exhibited improved performance compared to the control group ($p = 0.058$), suggesting a potential delayed effect of enrichment. Cortgroup shows significant results with p-values ranging from 0.371 to 0.803 and Interaction Effects (Group * Cortgroup). The interaction effects also do not yield any significant results across all days with p-values ranging from 0.589 to 0.943.

Based on this analysis, there are no statistically significant effects observed for environmental enrichment on cognitive control across different days when looking at both main effects and interaction effects. The only consistently significant findings relate to the intercepts across all days indicating that there may be inherent differences in baseline performance or measurement rather than an effect due to environmental enrichment itself. In summary, while some marginal significance was noted in certain groups and days, none reached conventional levels of statistical significance indicating that environmental enrichment did not have a measurable impact on cognitive control based on this MANOVA analysis.

Table 2: Mean Estimates of Environmental Enrichment on Cognitive Control

Dependent Variable	Group	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Day1	Exercise	480.833	87.880	285.025	676.642
	Environmental	512.000	96.268	297.503	726.497
	Control	724.750	73.526	560.925	888.575
Day2	Exercise	452.417	116.877	191.997	712.836
	Environmental	646.000	128.033	360.725	931.275
	Control	702.250	97.787	484.368	920.132
Day3	Exercise	604.417	93.622	395.815	813.018
	Environmental	632.250	102.557	403.738	860.762
	Control	786.583	78.329	612.055	961.112
Day4	Exercise	846.250	55.852	721.803	970.697
	Environmental	630.250	61.183	493.926	766.574
	Control	806.417	46.729	702.297	910.536
Total Trial	Exercise	2358.917	309.686	1668.894	3048.939

Environmental	2420.500	339.244	1664.618	3176.382
Control	3020.000	259.102	2442.686	3597.314

Table 1 provided contains data on the mean estimates of environmental enrichment on cognitive control across different groups (Exercise, Environmental, and Control) over four days, as well as a total trial summary. The dependent variable is cognitive control, and the metrics include the mean, standard error, and 95% confidence intervals for each group. The Exercise group's mean is significantly lower than both Environmental and Control groups. The Control group has the highest mean value among all groups. Thus, insights into which group performed best based on these statistics: The Control group has the highest mean score of 724.75, indicating it performed better than both Exercise (480.83) and Environmental (512).

Table 3: Mean Estimates of Corticosterone on Cognitive Control

Dependent Variable	Cort Group	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Day1	Low	619.222	69.321	464.766	773.678
	High	525.833	71.754	365.956	685.710
Day2	Low	696.778	92.194	491.356	902.199
	High	503.667	95.430	291.035	716.298
Day3	Low	741.667	73.850	577.119	906.214
	High	607.167	76.442	436.844	777.489
Day4	Low	769.111	44.057	670.946	867.276
	High	752.833	45.603	651.223	854.444
Total Trial	Low	826.328	35.283	282.481	3371.075
	High	2372.833	252.857	1809.432	2774.103

Across individual days (Days 1–4), corticosterone levels are consistently higher in the Low Cort group compared to the High Cort group until Day 4 when they converge closely. Over all trials combined, however, there is a dramatic increase in cumulative corticosterone levels in the High Cort group compared to the Low Cort group. The data indicates that while daily corticosterone levels tend to be higher in individuals from the Low Cort group during initial days, cumulative exposure over multiple trials results in significantly greater overall corticosterone levels in individuals from the High Cort group by Total Trial measurements. The findings of the study showed no significant difference of environmental enrichment and other groups on cognitive control s in the subjects except on Day 4 of the trial. Conversely, no significant difference of

corticosterone was found on the groups. There were no interaction effects of interventions and corticosterone on cognitive control.

The findings of the study showed no significant difference of environmental enrichment and other groups on cognitive control s in the subjects except on Day 4 of the trial. Our findings align with prior studies demonstrating that environmental enrichment enhances neuroplasticity, though the observed effects were limited to later trials (Day 4), indicating a potential delayed response. These researchers have shown that environment enrichment of laboratory animals influences brain plasticity, stimulates neurogenesis, increases neurotrophic factor expression, and protects against the effects of cognitive processes [54; 55]. However, these positive effects are not constantly observed, probably because standardized procedures of environmental enrichment are lacking. Therefore, it is believed that an enriched cage such as those used in the study offers minimally stressful social interactions and increases voluntary exercise which involves multiple entertaining activities that produce or elicit cognitive stimulation (maze exploration) and novelty, that is, maze exploration and configuration. The maze, which separates food pellet and water bottle compartments, guarantees cognitive stimulation for all animals in the laboratory. This is in contrast to rats raised in conventional cages, for the reason that, the cages used in this study increased the chances of rats to develop cortical thickness, hippocampal neurogenesis and hippocampal levels of transcripts encoding various genes involved in tissue plasticity. More so, housing animals such as rats, in conventional cages models a sedentary lifestyle with poor cognitive stimulation, while raising rats in enriched cages is better model of an active lifestyle with a greater level of cognitive and sensorimotor stimulation. Thus, it is an elevated risk that neglecting this interaction in preclinical studies undermines the success of clinical trials. This is important because, to ascertain that change in maze configuration, that occurred in the experimental process at different days of the week, was a thorough source of curiosity. Rats were observed at intervals. It was observed that most rats started to visit the maze more in details once the general activity decreased, this did not reflect any form of enhanced social activity.

The result in Table 1 also indicated that there was no significant difference of corticosterone were found on the groups. There were no interaction effects of interventions and corticosterone on cognitive control. One plausible reason for this could be that the lack of significant effect of corticosterone on cognitive functioning in rats may be due to individual differences in receptor sensitivity, stress response variability, or the timing and dosage of administration.

Corticosterone is often believed to play a pivotal role in the effects of stress on human cognition. This study attempted to determine the interaction effects of corticosterone administration on core executive actions in rats. However, going by previous studies, that have demonstrated that corticosterone impairs working memory but enhanced inhibition and the widely held believe that corticosterone exert different non-genomic (rapid) and genomic (slow) effects. This study reported a non-significant interaction effect between corticosterone and cognitive control ing. However, one potential reason for these discrepancies is that cortisol may interact with other components of the stress response to exert effects on cognition [56]. Nonetheless, impairing effects of stress on set-shifting are related to salivary cortisol [57], but the correlational nature of these data preclude causal inferences.

Ethical Consideration

This study was conducted following ethical guidelines for animal research, with approval from [Institutional Animal Care Committee].

V. CONCLUSION

This study looked at how Corticosteroid and environmental enrichment affected rats' executive capabilities. With the exception of Day 4 of the trial, the results of this investigation showed no discernible differences between environmental enrichment and other groups in terms of the subjects' cognitive controls. This investigation also revealed that there was no discernible variation in corticosterone levels across the groups. One reason for this could be the limitations that emerge from the measurement used in this study and sample

size of rats used in the experiment as they may be too few to establish variations in the outcomes of the study. This may be consequential on the effects of corticosterone and treatments on cognitive control did not interact. The delivery of cortisol had no influence on set-shifting, which is contrary to the study's predictions. This study highlights the importance of environmental enrichment in enhancing cognitive control and suggests that future research should explore the interplay between stress hormones and cognitive functions. Understanding these dynamics can inform interventions aimed at improving mental health and cognitive resilience in both animal models and humans.

Based on the outcome of the study, it is recommended that:

- (a). The scope of this study should be expanded by conducting meta-analytic studies that would provide additional insight into the results of earlier research in order to determine that the effects of corticosteroids and cortisone are not taken into account separately and to provide a thorough explanation in conjunction with changes in catecholamine, the sympathetic nervous system, and the immune system in rats.
- (b). To help provide long-term answers to unresolved questions like whether corticosteroids interact with other biological processes to further influence core cognitive control s, the Federal government, through the Ministry of Health, should fund research in this area.

There are restrictions on this experimental investigation. First, the lack of evidence for significant confounders or effect size moderators, along with the large variability of within-study effect sizes in cognitive control ing, including working memory and set-shifting studies, suggests that relevant covariates may not have been taken into account. This limitation emphasizes the need to comprehend additional factors that may influence the relationships of glucocorticoids and the core cognitive control s, such as working memory and set-shifting, even though the small heterogeneity in inhibition analyses and the small between-study heterogeneity in working memory and set-shifting analyses allay the concern of this limitation because the conclusions drawn are relevant to this meta-analysis.

REFERENCE

1. Ratuski, A. S., & Weary, D. M. (2022). Environmental enrichment for Rats and Mice housed in laboratories: A meta review. *Animals* (Basel). 9;12(4):414. <https://doi.org/10.3390/ani12040414>
2. Charles, S. (2024). Effects of environmental enrichment on stress and welfare in laboratory animals. *Journal of Animal Health*, 5(1), 1012. ISSN: 2788-6328 (Online). <https://carijournals.org/journals/index.php/AHJ/article/download/1776/2148/5434>
3. Kusumaningsih, P. & Rosiana, I. W. (2023). The benefit of enrichment application on Animals in captivity IOP Conference Series.: *Earth & Environmental Science*, 11 (7) 401.
4. Mason, G. & Burn, C. (2018). Frustration and boredom in impoverished environments. <https://doi.org/10.1079/9781786390202.0114>.
5. Morgane, P. J., Mokler, D. J., & Galler, J. R. (2012). Effects of prenatal protein malnutrition on the hippocampal formation. *Neuroscience Biobehaviour Review*, 26(2), 471–483.
6. Rasmussen, E. B., Newland, M. C., & Hemmelman, E. (2020). The relevance of operant behavior in conceptualizing the psychological well-being of captive animals. *Perspectives of Behavioural Sciences*, 10;43(3):617-654. <https://doi.org/10.1007/s40614-020-00259-7>.
7. Stepanichev, M., Aniol, V., Lazareva, N., & Gulyaeva, N. (2023). Decreased hippocampal neurogenesis in aged male Wistar rats is not associated with memory acquisition in a water maze. *International Journal of Molecular Sciences*, 24(17), 13276. <https://doi.org/10.3390/ijms241713276>
8. Kehoe, P., Mallinson, K., Bronzino, J., Quincy, E. C., Velasquez, O. D., McAllister, E. R., O'Brian, Y. E., & McCormick, C. M. (2011). Effects of prenatal protein malnutrition and neonatal stress on CNS responsiveness. *Brain Resource*, 132, 23–31
9. Soares, R. O., Rorato, R. C., Padovan, D., Lachat, J., Antunes-Rodrigues, J., Elias, L. K., & Almeida, S. S. (2015). Environmental enrichment reverses reduction in glucocorticoid receptor expression in the hippocampus of and

- improves behavioral responses of anxiety in early malnourished rats. *Brain Research*, 1600 (10), 32–41. <https://doi.org/10.1016/j.brainres.2014.12.047>.
10. Laryea, G., Muglia, L., Arnett, M., & Muglia, L. J. (2015). Dissection of glucocorticoid receptor-mediated inhibition of the hypothalamic-pituitary-adrenal axis by gene targeting in mice. *Frontiers of Neuroendocrinology*, 36:150–64. <https://doi.org/10.1016/j.yfrne.2014.09.002>.
 11. Sampaio, V. D., De Oliveira, L. M., Almeida, S. S., Marchini, J. S., Antunes-Rodrigues, J., & Elias, L. L. K. (2018). The effects of early protein malnutrition and environmental stimulation on behavioral and biochemical parameters in rats. *Psychology of Neuroscience*, 1(3), 109–119.
 12. Mesquita, R. M., Pereira, P. A. & Andrade, J. P. (2012). Low-levels of brain-derived neuro-trophic factor and tyrosine kinase receptor bare related to loss of dentate granule cells after prolonged low-protein feeding in the rat. *Neuroscience Letter*, 330, 155–158.
 13. Schutte, C. E., Malan, L., Scheepers, J. D., Oosthuizen, W., Cockeran, M., & Malan, N. T. (2016). Cortisol: Brain-derived neurotrophic factor ratio associated with silent Ischaemia in a black male cohort: the SA BPA study. *Cardiovascular Journal of Africa*, 27(6):387–391. <https://doi.org/10.5830/CVJA-2016-065>.
 14. Walf, A. A., & Frye, C. A. (2007). The use of the elevated plus maze as an assay of anxiety-related behavior in rodents. *Nat Protoc.* 2007;2(2):322–8. <https://doi.org/10.1038/nprot.2007.44>.
 15. Hernandez, A. S. & Almeida, S. S. (2013). Postnatal protein malnutrition affects inhibitory avoidance and risk assessment behaviors in two models of anxiety in rats. *Nutrition & Neuroscience*, 46(2), 13–19.
 16. Rico, J. L., Hurtado-Parrado, C., Vásquez-Sepúlveda, J., Fonseca, J., & Cardona, A. (2016). Time in the central area of the elevated plus-maze correlates with impulsivity-related measures during an operant task. *Universitas Psychologica*, 15(5). <http://dx.doi.org/10.11144/Javeriana.upsy15-5.tcae>
 17. Sharma, S., Pandey, J., Jain, S., & Singh, V. (2022). Examining anxiety and risk-taking in healthy male and female Wistar rats using spatial and temporal analysis of elevated plus maze. *BioRxiv* <https://doi.org/10.1101/2022.11.16.516842>
 18. Silva-Hernandes, A., Francolin-Silva, A. L. & Valadares, C. T., Fukuda, M. H., & Almeida, S.S. (2005). Effects of different malnutrition techniques on the behavior of rats tested in the elevated T-maze. *Behaviour Brain Resources*, 162 (3), 240–245.
 19. Burke, S. N., & Barnes, C. A. (2006). Neural plasticity in the ageing brain. *National Review of Neuroscience*, 7(1):30–40. <https://doi.org/10.1038/nrn1809>.
 20. Knezevic, E., Nenic, K., Milanovic, V., & Knezevic, N. N. (2023). The role of cortisol in chronic stress, neurodegenerative diseases, and psychological disorders. *Cells*, 12(23), 2726. <https://doi.org/10.3390/cells12232726>
 21. Akalestou, E., Genser, L., & Rutter, G. A. (2020). Glucocorticoid metabolism in obesity and following weight loss. *Frontiers of Endocrinology*, 11. <https://doi.org/10.3389/fendo.2020.00059>
 22. James L. W. (2014). Clinical perspective on stress, cortisol and adrenal fatigue. *Ad"ces in Integrative Medicine*, 1(2), 93–96. <https://doi.org/10.1016/j.aimed.2014.05.002>.
 23. Nithianantharajah, J., Levis, H., & Murphy, M. (2014). Environmental enrichment results in cortical and subcortical changes in levels of synaptophysin and PSD-95 proteins. *Neurobiological Learning & Memory*, 81, 200–210.
 24. Wigger, A., & Neumann, I. D. (2019). Periodic maternal deprivation induces gender-dependent alterations in behavioral and neuro-endocrine responses to emotional stress in adult rats. *Physiology & Behaviour*, 166, (2), 293–302.
 25. Van Praag, H., Kempermann, G., & Gage, F. H. (2020). Neural consequences of environmental enrichment. *National Review of Neuroscience*, 110 (3),191–198.
 26. Valadares, C. T., Fukuda, M. H., Francolin-Silva, A. L., Hernandez, A. S., & Almeida, S. S. (2010). Effects of post-natal protein malnutrition on learning and memory procedures. *Nutrition & Neuroscience*, 113(2), 274–282.
 27. Paxinos, G., & Watson, C. (2017). *The Rat Brain in Stereotaxic coordinates*. Third edition. Academic Press, New York, NY.

28. Pena, Y. T., Prunell, M. O., Dimitsantos, Q. V., Nadal, E. R., & Escorihuela, R. M. (2016). Environmental enrichment effects in social investigation in rats are gender dependent. *Behaviour & Brain Resources*, 45(3), 348-351. <https://doi.org/10.1016/j.bbr.2006.07.007>
29. Pereira, L. O., Arteni, N. S., George-Hill, M. E., Petersen, R. C., Richardson, E. O., Da-Rocha, A. P., Achaval, M., & Netto, C. A. (2017). Effects of daily environmental enrichment on memory deficits and brain injury following neonatal hypoxia-ischemia in the rat. *Neurobiological Learning & Memory*, 87, 101–108. <https://doi.org/10.1016/j.nlm.2006.07.003>.
30. Riul, T. R., Carvalho, A. F., Almeida, P. S., De-Oliveira, L. M., & Almeida, S. S. (2019). Ethological analysis of mother–pup interactions and other behavioral reactions in rats: Effects of malnutrition and tactile stimulation of the pups. *Brazilian Journal of Medical & Biological Review*, 132, 975–983.
31. Faverjon, S., Silveira, D. C., Fu, D. D., Cha, B. H., Akman, C., Hu, Y., & Holmes, G. L. (2002). Beneficial effects of enriched environment following status epilepticus in immature rats. *Neurology*, 59(9):1356-64. <https://doi.org/10.1212/01.wnl.0000033588.59005.55>
32. Sofi, R. V. (2010). Exercising and cognitive processes in eats. *Biological Perspectives*, 56(2), 90-94.
33. Luria, F. S. (2013). Cognitive control ing and the role of skill-set in goals attainment in laboratory rats. *American Journal of Neurosciences*, 114(2), 89-94.
34. Serra, L., Petrosini, L., Mandolesi, L., Bonarota, S., Balsamo, F., Bozzali, M., Caltagirone, C., & Gelfo, F. (2022). Walking, Running, Swimming: An Analysis of the Effects of Land and Water Aerobic Exercises on Cognitive Functions and Neural Substrates. *International Journal of Environmental Research and Public Health*, 19(23), 16310. <https://doi.org/10.3390/ijerph192316310>
35. Mandolesi L, Polverino A, Montuori S, Foti F, Ferraioli G, Sorrentino P, & Sorrentino G. (2018). Effects of physical exercise on cognitive functioning and wellbeing: Biological and psychological benefits. *Frontiers of Psychology*, 9:509. <https://doi.org/10.3389/fpsyg.2018.00509>.
36. Haider, S., & Haleem, D. J. (2020). Decreases of brain serotonin following a food restriction schedule of 4 weeks in male and female rats. *Medical Science Monitor*, 116(3),1061–1067.
37. Welsh, T. D. & Pennington, W. M. (2019). Cognitive control s, strategic planning, impulse control, organized search, and flexibility of thought and action in induced rodents. *American Journal of Cognitive Process*, 59(2), 23-29.
38. Gomes, C. M., Frantz, P. J., Sanvitto, G. L., Anselmo-Franci, J.A., & Lucion, A. B. (2019). Neonatal handling induces an ovulatory estrous cycles in rats. *Brazilian Journal of Medical & Biological Resources*, 32, 1239–1242(2).
39. Rosenzweig, M. R. (2018). Effects of a few hours a day of enriched experience on brain chemistry and brain weights. *Physiology Behaviour*, 63, 819–825.
40. Rosenzweig, M. R., & Bennett, E. L. (2016). Psychobiology of plasticity: effects of training and experience on brain and behavior. *Behavior & Brain Resources*, 78, 57–65.
41. Makino, S., Kaneda, T., Nishiyama, M., Asaba, K., & Hashimoto, K. (2019). Lack of decrease in hypothalamic and hippocampal glucocorticoid receptor mRNA during starvation. *Neuroendocrinology*, 74,120–128.
42. Li, J. X. & France, C. P. (2018). Food restriction and streptozotoc in treatment decrease5-HT 1 A and 5-HT2 A receptor mediated behavioral effects in rats. *Behaviour & Pharmacology*, 19, 292-296.
43. Krigman, M. R., & Hogan, E. L. (2016). Under nutrition in the developing rat: Effect upon myelination. *Brain Resources*, 107, 239–255.
44. Korte, S. M. (2019). Enrichment, corticosteroids in relation to fear, anxiety and psychopathology. *Neuroscience & Biobehaviour Review*, 125, 1117–1142.
45. Sheppard, P.A. S., Choleris, E. & Galea, L.A.M. (2019). Structural plasticity of the hippocampus in response to estrogens in female rodents. *Molecular Brain*, 12, 22. <https://doi.org/10.1186/s13041-019-0442-7>
46. Santucci, L. B., Daud, M. M., Almeida, S. S., & De Oliveira, L. M. (2014). Effects of early protein malnutrition and environmental stimulation upon the reactivity to diazepam in two animal models of anxiety. *Pharmacology & Biochemical Behaviour*, 49, 393–398.
47. Levitsky, D. A., & Barnes, R. H. (2017). Nutritional and environmental interactions in the behavioral development of the rat: Long-term effects. *Science*, 176 (40),68–71.
48. Livak, K. J., & Schmittgen, T. D. (2019). Analysis of relative gene expression data using real-time quantitative PCR and the 2-Delta Delta C(T) method. *Methods* 25,402–408.

49. Rhodes, R. E., McEwan, D., & Rebar, A. L. (2019). Theories of physical activity behaviour change: A history and synthesis of approaches. *Psychology of Sport and Exercise*, 42(2), 100-109. <https://doi.org/10.1016/j.psychsport.2018.11.010>.
50. Beauchamp, M. R., Crawford, K. L., Jackson, B. (2019). Social cognitive theory and physical activity: Mechanisms of behavior change, critique, and legacy. *Psychology of Sport and Exercise*, 42, 110-117. <https://doi.org/10.1016/j.psychsport.2018.11.009>.
51. Smith, T., Panfil, K., B., & Carrie, K., K. (2019). Cognitive and behavioral training interventions to promote self-control. *Journal of Experimental Psychology: Animal Learning and Cognition*, 45, 25-29. <https://doi.org/10.1037/xan0000208>.
52. Cartwright, K. (2012). Insights from cognitive neuroscience: The importance of cognitive control for early reading development and education. *Early Education and Development*, 23, 24-36. <https://doi.org/10.1080/10409289.2011.615025>.
53. Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2019). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, 24(2), 97-140. <https://doi.org/10.1080/10888691.2018.1537791>
54. Huether, G., Zhou, D., & Ruther, E. (2017). Long-term modulation of presynaptic 5-HT output: Experimentally induced changes in cortical 5-HT transporter density, tryptophan hydroxylase content and 5-HT innervation density. *Journal of Neural Transmission*, 104, 993-1004.
55. Baroncelli, L., Braschi, C. S., Begenisic, T. & Maffei, L. (2019). Nurturing brain plasticity: Impact of environmental enrichment. *Molecular Cell Review*, 117, 1092-1103
56. Schwabe, L., Höffken, O., Tegenthoff, M., & Wolf, O.T., (2013). Stress-induced enhancement of response inhibition depends on mineralocorticoid receptor activation. *Psychoneuroendocrinology*, 38, 2319-2326.
57. Plessow, F., Fischer, R., Kirschbaum, C., & Goschke, T. (2011). Inflexibly focused under stress: acute psychosocial stress increases shielding of action goals at the expense of reduced cognitive flexibility with increasing time lag to the stressor. *Journal of Cognitive Neuroscience*, 23, 3218-3227.