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A Statistical Study Of Heart Rate And Blood Pressure Under Stimulus And Recovery

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Abstract
This study examines gender-based cardiovascular responses to auditory and physical stimuli in 60 participants (30 males, 30 females). Heart rate and systolic blood pressure were measured during exposure to different music tempos, a Treadmill Test (TMT), and real-world exercise. Linear regression revealed that females showed greater heart rate sensitivity to music, while males responded more strongly to ballads but suppressed responses to hard rock. Post-exercise analysis using Welch's t-test showed that males recovered heart rate faster, whereas females maintained elevated levels longer. Additionally, males exhibited significantly higher systolic blood pressure post-exercise compared to females. The findings highlight distinct gender-based patterns in cardiovascular reactivity and recovery, with implications for personalized training, rehabilitation, and music-based therapeutic interventions.

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I. Introduction

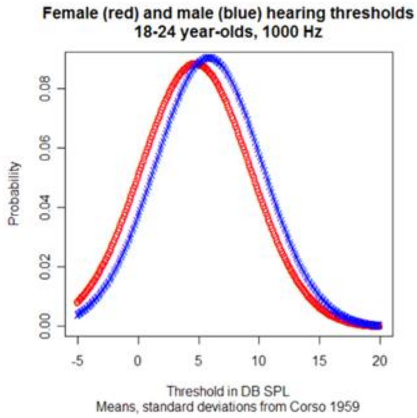
Understanding how the human body physiologically responds to both auditory and physical stimuli is a key area of research in biomedical and health sciences (Kim et al., 2015). Heart rate and systolic blood pressure are widely accepted indicators of cardiovascular performance, often used to assess fitness, stress response, and overall well-being [1]. By studying the body's response to common yet distinct stimuli—music and physical activity—this research seeks to understand how males and females differ in terms of heart rate reactivity and recovery patterns.

The project focuses on analyzing the cardiovascular response of individuals to various physical and auditory stimuli, using inferential statistical methods. It aims to explore gender-based differences in heart rate and systolic blood pressure under specific conditions, including exposure to different music tempos, treadmill exercise (TMT), and post-exercise recovery in fitness environments such as parks and gyms. It will involve gathering data from 60 participants (30 males and 30 females), including heart rate and blood pressure measurements under controlled conditions. Statistical tools like the two-tailed t-test will be used to identify whether the observed differences are statistically significant.

In particular, the study integrates gender-based comparative analysis with empirical methods, aiming to understand whether biological and perceptual differences affect cardiovascular recovery patterns.

II. Importance

Past research suggests that auditory stimuli—particularly tempo and pitch—can influence the autonomic nervous system, thereby modulating cardiovascular output [2]. For instance, faster tempos have been associated with increased heart rate and arousal, while slower tempos often produce calming effects [3].



Moreover, evolutionary psychology indicates that women may exhibit heightened sensitivity to higher-pitched auditory cues, possibly influencing their physiological response to certain genres of music [4].

If distinct gender-based responses are identified, music therapy protocols can be tailored more effectively, especially for stress reduction or cardiovascular regulation.
Distribution of Hearing Thresholds at 1000 Hz in Young Adults (Aged 18–24)
http://itre.cis.upenn.edu/~myl/languagelog/archives/003419.html

Another component of this study involves a physical stressor- the Treadmill Test (TMT), a standard diagnostic used to assess cardiovascular endurance and stress recovery. Participants from the same age group are monitored for heart rate and recovery time after a treadmill workout. TMT is a standard tool in cardiology. Understanding whether men and women differ in their cardiovascular recovery rates can help refine normal ranges for diagnostic interpretation. Furthermore, the data can inform the design of gender-sensitive plans, especially for mid-life adults who may require different recovery times.

To simulate real-life conditions, participants are observed before and after exercise in open walking parks. Systolic blood pressure readings are used to compare gendered recovery trends in natural settings, helping assess whether responses seen in clinical environments hold true in everyday contexts.

III. Objectives

1. Apply Linear regression, and differential expressed as rate of change to analyse gender-based differences in heart rate responses to varying music tempos (ballads vs. hard rock), thereby identifying whether auditory stimuli elicit statistically significant variations in cardiovascular activity.
2. Use statistical analysis to compare post-exercise heart rate recovery patterns between male and female participants following a standardized Treadmill Test (TMT), aiming to evaluate differences in cardiovascular resilience and stress recovery.
3. Assess systolic blood pressure recovery in real-world environments (e.g., walking parks) by recording pre- and post-exercise values across genders, thereby evaluating whether gender-based physiological responses observed in clinical settings extend to naturalistic contexts.

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}}$$

IV. Methodology Of Study

OBJECTIVE-1: Linear regression, and differential expressed as rate of change

These methods are used to analyse how heart rate (BPM) changes in response to variations in music tempo (BPM) for male and female participants.

The slope of the line represents how much the heart rate increases per unit increase in tempo. By comparing the slopes for men and women, we can assess gender sensitivity to music tempo. Differentiation is used to represent the rate of change of heart rate with respect to tempo.

OBJECTIVE-2: T-Test for independent groups assuming that the variances are unequal (for heart rate before and after TMT)

This method is used to assess gender differences in cardiovascular recovery after physical exertion, specifically using post-exercise heart rate recovery data from the Treadmill Test (TMT).

The goal is to statistically verify if one gender demonstrates faster or more efficient recovery after physical activity, using heart rate as a key physiological indicator.

Recovery is measured at fixed intervals (heart rate 1 minute and 3 minutes post-exercise), and mean recovery rates are compared between male and female participants. [5]

OBJECTIVE-3: T-Test for independent groups assuming that the variances are unequal (for systolic blood pressure (SBP) monitoring before and after exercise such as walking or running)

Heart rate and systolic blood pressure are recorded pre- and post-activity in both settings. Mean recovery values are calculated and then compared between male and female participants using a two-tailed t-test, helping assess whether environmental factors influence gender-based physiological responses, such as blood pressure. The formula used for this objective will be the same as the one in OBJECTIVE-2.

V. Limitations

Limited Sample Size And Diversity:

The study may involve a relatively small number of participants, which can limit the generalizability of the findings. Additionally, if the sample lacks diversity in terms of age, fitness levels, and underlying health conditions, the results may not accurately reflect broader population trends.

Short-Term Observation Period:

Cardiovascular responses are measured during a single session or over a short duration, which may not account for individual day-to-day variability, hormonal cycles (especially in women), or longer-term adaptations to physical exertion or music exposure.

External Environmental And Psychological Factors:

Naturalistic settings like parks or gyms are subject to unpredictable variables that can influence heart rate and recovery. These uncontrolled factors might affect the accuracy and consistency of the results when comparing clinical and natural environments.

VI. Application Of Mathematical Tools

Objective-1:

Apply a two-tailed independent samples t-test to analyse gender-based differences in heart rate responses to varying music tempos (ballads vs. hard rock), thereby identifying whether auditory stimuli elicit statistically significant variations in cardiovascular activity.

This objective aims to evaluate whether there are significant gender-based differences in cardiovascular responses to varying music tempos. Music, as an auditory stimulus, has been shown to influence physiological parameters such as heart rate. In this study, participants were exposed to two types of music: a hard rock song with a tempo of 120 beats per minute (BPM) and a ballad with a tempo of 70 BPM.

The heart rates for both the genres, of the genders assessed in the study are given below:

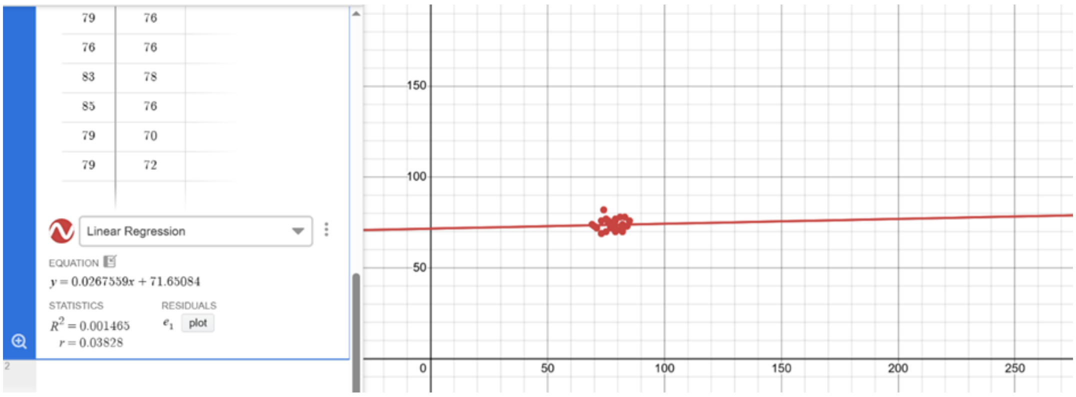
Participant ID	Gender	Resting Heart Rate (X)	Ballad genre Heart Rate (Y)	Rock genre Heart Rate
1	Female	73	76	83
2	Female	70	73	100
3	Female	75	77	87
4	Female	74	82	80
5	Female	83	73	93
6	Female	84	73	92
7	Female	81	78	85
8	Female	77	73	87
9	Female	73	69	80
10	Female	73	69	93
11	Female	71	72	89
12	Female	78	75	87
13	Female	82	72	82
14	Female	69	74	88
15	Female	76	75	84
16	Female	76	75	85
17	Female	82	70	86
18	Female	77	72	81
19	Female	82	74	90
20	Female	79	77	85
21	Female	82	73	85
22	Female	75	70	83
23	Female	80	71	93
24	Female	82	71	93
25	Female	79	76	87
26	Female	76	76	92
27	Female	83	78	94
28	Female	85	76	83
29	Female	79	70	93
30	Female	79	72	86

Female Participant Data Collected

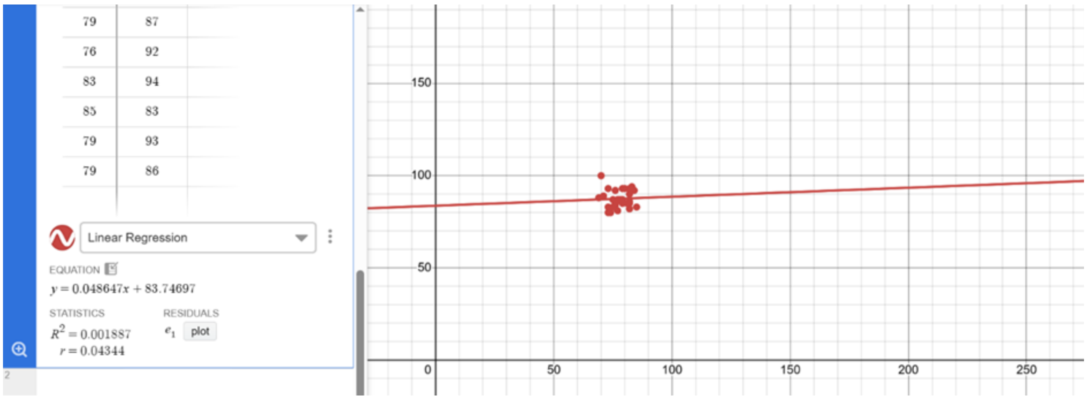
Participant ID	Gender	Resting Heart Rate	Rock genre Heart Rate	Ballad Heart Rate
1	Male	70	80	68
2	Male	73	81	66
3	Male	67	87	70
4	Male	70	84	68
5	Male	69	84	68
6	Male	74	84	66
7	Male	65	91	67
8	Male	74	79	71
9	Male	71	86	66
10	Male	70	84	67
11	Male	71	84	64
12	Male	67	83	64
13	Male	68	85	64
14	Male	69	80	71
15	Male	72	82	64
16	Male	77	86	67
17	Male	74	91	66
18	Male	76	80	72
19	Male	72	86	72
20	Male	73	77	72
21	Male	67	78	63
22	Male	72	86	64
23	Male	68	84	67
24	Male	69	90	64
25	Male	69	86	70
26	Male	72	88	68
27	Male	67	80	67
28	Male	67	81	65
29	Male	70	84	66
30	Male	70	87	68

Male Participant Data Collected

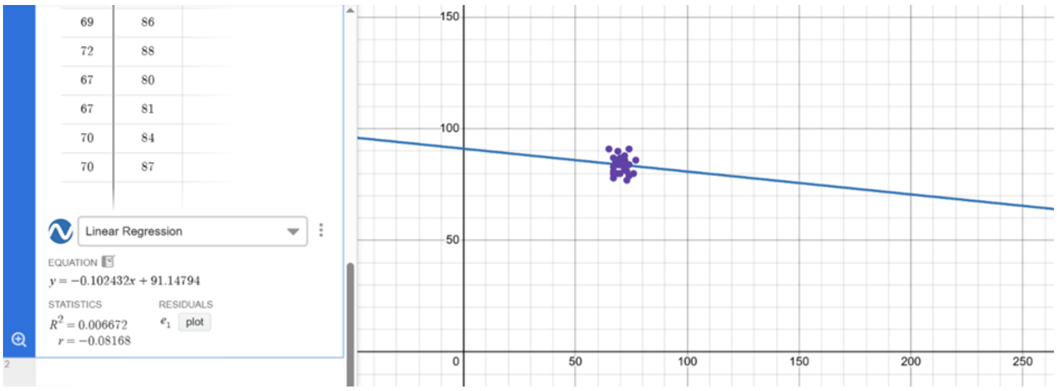
For the next part of this objective, in order to analyse the relationship between the change in tempo and the corresponding change in heart rate, the data collected was inputted onto Desmos, an online graphing calculator. Using its regression feature, a linear regression model was generated and used to determine the line of best fit for the data. This model helped identify the equation that best represents the trend in the data, showing how heart rate tends to respond as musical tempo increases.



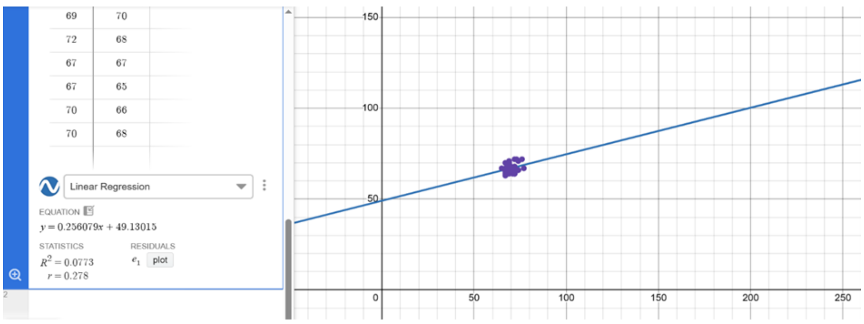
The resulting equation was in the form of **y = mx + c**, where *y* represents the change in heart rate, *x* is the change in tempo, *m* is the slope of the line indicating the rate of change, and *c* is the y-intercept.



Rate of Change of **female** heart rate with respect to the rate of change of music tempo of a Ballad genre song
Rate of Change of **female** heart rate with respect to the rate of change of music tempo of Hard Rock genre song



Rate of Change of **male** heart rate with respect to the rate of change of music tempo of Hard Rock genre song
Rate of Change of **male** heart rate with respect to the rate of change of music tempo of Ballad genre song



Equation representing the Rate of Change of **female** heart rate with respect to the rate of change of music tempo of a Ballad genre song is **$y = 0.02675x + 71.65084$**

Equation representing the Rate of Change of **female** heart rate with respect to the rate of change of music tempo of Hard Rock genre song is **$y = 0.0486x + 83.7469$**

Equation representing the Rate of Change of **male** heart rate with respect to the rate of change of music tempo of Hard Rock genre song is **$y = -0.102432x + 91.14794$**

Equation representing the Rate of Change of **male** heart rate with respect to the rate of change of music tempo of Ballad genre song is **$y = 0.256079x + 49.13015$**

Analysis of the data

Females show a positive heart rate response to both genres, with a higher sensitivity to hard rock (slope = 0.0486) than to ballads (slope = 0.02675). This suggests that female heart rates increase more when the tempo increases, particularly for faster, more intense music.

Males, on the other hand, show contrasting responses:

- A strong positive response to ballads (slope = 0.25608) — meaning male heart rate increases significantly as tempo increases within the ballad genre.
- A negative response to hard rock (slope = -0.10243) — suggesting heart rates decrease as tempo increases in hard rock. This could indicate overstimulation or possibly a stress-related physiological suppression.

The stark difference between male responses to ballads versus hard rock implies a genre-dependent effect on heart rate.

Comparing across genders:

Men and women exhibit fundamentally different responses to music-based stimuli due to a confluence of neurological structure, hormonal influence, auditory sensitivity, and evolutionary adaptations. Women generally show heightened emotional and physiological reactivity to music, particularly ballads and emotionally evocative melodies. This is largely due to the larger and more active limbic structures in the female brain, such as the amygdala and hippocampus, which process emotion and memory more intensely. Hormonal differences, especially the influence of estrogen, increase neural excitability and deepen emotional processing. Moreover, women possess greater sensitivity to high-frequency sounds — an evolutionary trait believed to enhance maternal responsiveness to infant cries. This sensitivity, rooted in cochlear mechanics and cortical processing, leads to increased alertness and, subsequently, a more pronounced autonomic response, including elevated heart rate when listening to high-pitched or emotionally intense music.

In contrast, men tend to have a more analytical and less emotionally saturated response to music. The male brain typically shows greater lateralization, with emotional processing being more confined to one hemisphere and less limbic involvement. Additionally, the male auditory system is less sensitive to high-pitched frequencies, reducing the chance of subconscious alertness to emotionally charged tones in ballads. Men often respond more strongly to music with rhythmic complexity or lower-pitched frequencies, such as bass-heavy or percussion-driven tracks, which activate brain areas related to movement and structure rather than emotion. Testosterone also dampens emotional reactivity, contributing to a relatively stable heart rate and reduced physiological fluctuation during music exposure.

Thus, while women are evolutionarily and biologically primed to respond more emotionally and physiologically to melodic and high-pitched stimuli, men display a more moderated, rhythm-oriented reaction, driven by cognitive and structural auditory processing. These gender-based divergences underscore the role of both nature and nurture in shaping how music is perceived and internalized.

This objective treats the slope as the instantaneous rate of change of heart rate per BPM of music tempo, gives a quantitative and interpretable measurement of musical responsiveness.

Objective-2:

Use statistical analysis to compare post-exercise heart rate recovery patterns between male and female participants following a standardized Treadmill Test (TMT), aiming to evaluate differences in cardiovascular

Participant ID	Gender	Resting heart rate	Peak heart rate (TMT)	Recovery heart rate (1 minute)	Recovery heart rate (3 minutes)	Age
1	Female	80	187	151	127	28
2	Female	68	176	134	90	31
3	Female	80	173	146	108	51
4	Female	93	169	120	104	50
5	Female	99	184	148	107	38
6	Female	98	184	162	115	55
7	Female	80	162	129	99	28
8	Female	82	171	129	105	25
9	Female	97	164	116	103	31
10	Female	100	179	148	113	22
11	Female	83	179	148	113	28
12	Female	100	179	126	111	42
13	Female	76	168	136	110	44
14	Female	85	175	142	119	37
15	Female	91	182	150	125	29
16	Female	88	177	143	120	33
17	Female	72	165	132	108	48
18	Female	84	171	138	113	26
19	Female	79	191	140	115	41
20	Female	87	180	147	121	39
21	Female	95	185	155	130	27
22	Female	81	172	139	114	35
23	Female	92	178	144	118	30
24	Female	78	174	137	112	49
25	Female	83	170	136	111	46
26	Female	89	182	151	124	34
27	Female	90	177	149	122	43
28	Female	86	180	146	118	31
29	Female	74	167	135	109	36
30	Female	82	171	141	116	40

This objective aims to quantitatively evaluate gender-based differences in cardiovascular recovery following a standardized Treadmill Test (TMT) by analyzing post-exercise heart rate patterns. Specifically, the 1-minute recovery heart rate will be compared between male and female participants using an independent sample t-test under the assumption of unequal variances (Welch's t-test). The analysis will employ the statistical formula.

The tables above show the gender-based data of resting heart rate prior to the TMT, peak heart rate, and the recovery heart rate after 1 and 3 minutes. The analysis will employ the statistical formula:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\surd(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2})} \quad [5]$$

For this objective, the recovery heart rate after 1 minute will be compared to check if there is any statistically significant difference in the recovery heart rate at 1 minute.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$$t = \frac{140.60 - 131.63}{\sqrt{\frac{105.14}{30} + \frac{167.96}{30}}} \approx 2.972$$

Let μ_F = mean 1-minute recovery HR for females, μ_M = mean 1-minute recovery HR for males.

- $H_0 : \mu_F = \mu_M$ (no difference)
- $H_a : \mu_F \neq \mu_M$ (two-tailed — difference exists)

α = 0.05

Female mean ($\bar{X}_1$) = **140.60 bpm**

Male mean ($\bar{X}_2$) = **131.63 bpm**

Female variance (s_1^2) = **105.14**

Male variance (s_2^2) = **167.96**

$$n_1 = 30,\ n_2 = 30$$

N = 60 Degree of Freedom (Df) = N – 1 = 59

A P-Value calculator [6] was used in order to get the p value by using the t-statistic (2.972) at the Degree of Freedom (59).

The two-tailed P value equals 0.0043

The statistical analysis using the t-test revealed a significant difference in 1-minute post-exercise heart rate recovery between male and female participants following a standardized Treadmill Test (TMT). Since $p < 0.05$, the null hypothesis of equal mean recovery heart rates was rejected.

The results indicate that, on average, female participants exhibited a higher heart rate one minute after exercise cessation, which are statistically significant. Physiologically, this suggests potential differences in autonomic nervous system regulation and cardiovascular recovery kinetics between genders. A higher residual heart rate at 1 minute may indicate either slower parasympathetic reactivation or differences in metabolic demand and thermoregulation in females under similar exercise loads.

From a cardiovascular resilience perspective, this finding implies that male participants recovered more rapidly in the immediate post-exercise period, while females maintained elevated rates for longer. This pattern could be influenced by factors such as stroke volume capacity, oxygen debt repayment, and hormonal modulation of recovery.

In clinical and sports science contexts, such differences highlight the importance of gender-specific recovery monitoring and could inform personalized training protocols and cardiac rehabilitation programs.

OBJECTIVE-3:

Assess systolic blood pressure in real-world environments (e.g., walking parks) by recording pre- and post-exercise values across genders, thereby evaluating whether gender-based physiological responses to stimulus observed in clinical settings extend to naturalistic contexts.

Participant ID	Gender	Pre-Exercise Systolic Blood Pressure	Post-Exercise Systolic Blood Pressure	Age
1	Female	115	129	40
2	Female	113	128	29
3	Female	109	122	25
4	Female	116	131	42
5	Female	111	124	37
6	Female	114	128	28
7	Female	110	123	33
8	Female	117	132	41
9	Female	113	127	39
10	Female	112	125	35
11	Female	114	128	30
12	Female	109	122	26
13	Female	115	130	43
14	Female	111	125	38
15	Female	113	127	31
16	Female	108	121	27
17	Female	116	130	45
18	Female	110	124	34
19	Female	112	126	32
20	Female	114	129	47
21	Female	109	123	25
22	Female	115	129	36
23	Female	111	126	40
24	Female	113	127	28
25	Female	108	122	30
26	Female	116	131	44
27	Female	112	126	39
28	Female	110	124	33
29	Female	114	128	48
30	Female	109	123	26

Participant ID	Gender	Pre-Exercise Systolic Blood Pressure	Post-Exercise Systolic Blood Pressure	Age
1	Male	121	139	44
2	Male	124	139	34
3	Male	118	136	47
4	Male	117	134	38
5	Male	125	143	50
6	Male	119	136	31
7	Male	122	139	46
8	Male	116	133	27
9	Male	120	137	36
10	Male	118	134	29
11	Male	123	142	41
12	Male	115	132	28
13	Male	121	140	45
14	Male	119	136	37
15	Male	122	139	30
16	Male	117	134	43
17	Male	124	141	49
18	Male	118	134	33
19	Male	120	138	40
20	Male	115	131	26
21	Male	121	139	39
22	Male	119	137	35
23	Male	123	141	48
24	Male	117	134	32
25	Male	122	139	42
26	Male	118	135	27
27	Male	124	142	44
28	Male	116	132	31
29	Male	120	137	36
30	Male	119	135	29

This objective aims to quantitatively evaluate gender-based differences in systolic blood pressure (SBP) response to physical exertion in real-world environments (e.g., park walks). Specifically, the immediate post-exercise systolic blood pressure will be compared between male and female participants, to test whether exercise-induced cardiovascular responses differ significantly across genders.

The dataset records pre-exercise SBP (resting values) and post-exercise SBP (immediate values) across 30 male and 30 female participants aged 25–50 years.

An independent sample t-test with unequal variances (Welch's t-test) will be applied to compare the mean post-exercise SBP values between male and female groups. The statistical formula is:
[5]

For this objective, the systolic blood pressure measurements will be compared between the two groups to check if there is any statistically significant difference in systolic blood pressure, post exercise.

$$H_0 : \mu_f = \mu_m \text{ (no difference)}$$
$$H_1 : \mu_f \neq \mu_m \text{ (two-tailed — difference exists)}$$

α = 0.05

Female mean ($\bar{X}_f$) = **127.93 mmHg**

Male mean ($\bar{X}_m$) = **136.57 mmHg**

Female variance (s_f^2) = $9.76^2 = 95.14$

Male variance (s_m^2) = $7.09^2 = 50.27$

$n_f = 30, \ n_m = 30$

$$t = \frac{-8.64}{\sqrt{3.17 + 1.68}}$$

$$t = \frac{-8.64}{\sqrt{4.85}}$$

$$t = \frac{-8.64}{2.20} = -3.92$$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$$t = \frac{127.93 - 136.57}{\sqrt{\frac{95.14}{30} + \frac{50.27}{30}}}$$

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2})}}$$

N = 60 Degree of Freedom (Df) = N – 1 = 59

A P-Value calculator [6] was used in order to get the p value by using the t-statistic (-3.92) at the Degree of Freedom (59).

The two-tailed P value equals 0.0002

The statistical analysis using Welch's t-test revealed a significant difference in immediate post-exercise systolic blood pressure between male and female participants. Since $p < 0.05$, the null hypothesis of equal mean systolic blood pressure was rejected.

The results indicate that, on average, male participants exhibited a higher systolic blood pressure immediately after exercise compared to females, and this difference was statistically significant. Physiologically, this suggests that males may experience greater acute vascular responses or heightened sympathetic activation during exertion, leading to elevated post-exercise systolic pressures. In contrast, females demonstrated comparatively lower post-exercise SBP, which may reflect gender-specific differences in vascular compliance, hormonal influences (e.g., estrogen-mediated vasodilation), and peripheral resistance regulation.

From a cardiovascular performance perspective, these findings imply that men may demonstrate stronger pressure responses under exercise stress, while women may display relatively moderated blood pressure elevations. Such gender-based variations in blood pressure regulation could influence exercise tolerance, cardiovascular workload, and long-term vascular adaptations.

In clinical and sports science contexts, the results highlight the importance of considering gender when interpreting exercise blood pressure responses. These differences may inform individualized exercise prescriptions, risk stratification, and monitoring strategies in both athletic training and cardiac rehabilitation programs.

VII. Conclusion

This project has analyzed gender-based cardiovascular responses to both auditory and physical stimuli using inferential statistical methods, including linear regression and independent sample t-tests. The findings reveal that men and women respond differently to music tempo, treadmill exercise, and real-world physical exertion, highlighting the role of gender as a significant factor in cardiovascular performance and recovery.

With respect to auditory stimuli, females demonstrated a consistent increase in heart rate across both slow-tempo and fast-tempo music, with heightened sensitivity to hard rock. Males, on the other hand, exhibited contrasting patterns, showing strong heart rate reactivity to ballads but a negative response to hard rock, suggesting overstimulation or stress-related suppression. These results emphasize that biological and neurological differences shape how music influences cardiovascular activity across genders.

The analysis of post-exercise recovery through the Treadmill Test further established that males recovered more rapidly than females within the first minute after exercise. The statistically significant difference indicates that females maintained elevated heart rates for longer, possibly due to slower parasympathetic reactivation or higher metabolic demands. This highlights the need for gender-sensitive approaches in exercise recovery and rehabilitation planning.

Similarly, systolic blood pressure responses in real-world exercise conditions revealed that males experienced significantly higher post-exercise SBP compared to females. This pattern reflects greater sympathetic activation and vascular responses in men, whereas females showed more moderated increases, likely influenced by hormonal and vascular compliance factors.

Overall, this study demonstrates that gender plays a central role in shaping cardiovascular reactivity to both music and exercise. While women tend to show stronger emotional and physiological responses to auditory stimuli, men exhibit more pronounced blood pressure elevations and faster recovery rates following exertion. These findings suggest that incorporating gender-specific insights can improve the design of exercise regimens, stress management strategies, and even music therapy protocols. By integrating biological and perceptual differences, cardiovascular health interventions can become more personalized, effective, and equitable.

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