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Assessment of Heart Rate Variability during Activities of Daily Living

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ABSTRACT

This study examines heart rate variability (HRV) during selected daily activities (ADLs) using ECG and accelerometer measurements in 18 healthy males with an average age of27.2 years. HRV metrics, including RR, HR, LF, HF, and LF/HF ratio, were assessed under silence, conversation, and music conditions for 39 minutesover twelve stages of selected activities. The accelerometer was used to quantify the dynamics of the body. It was found that the HRV in these subjects did not have a significant difference between the three trials. However, individual differences existed, as evidenced by the results of this study, which characterized the cardiac 'stress' of ADLs in healthy individuals under varying conditions. Results also indicate that climbing stairs induces the highest sympathetic activation in HRV metrics, while sweeping and stacking activities maintain balanced autonomic engagement. These findings support sensor-based monitoring to assess physical strain in daily life; therefore, this would be useful reference data for future work.

Keywords: Heart Rate Variability, ECG, Accelerometer, Autonomic Nervous System, Daily Living Activities, Heart Rate

INTRODUCTION

As modern lifestyles become more sedentary and work-related stress rises, understanding the physiological impacts of everyday activities has become a growing area of interest. Heart Rate Variability (HRV) serves as a crucial non-invasive measure to examine how the autonomic nervous system responds to physical and emotional stressors, according to Heidelbach, Cysarz [1].The study of heart rate variability during activities of daily living (ADLs) is therefore a very importantapproachin understanding the heart and general human physiology. A number of devices, such as the electrocardiograph (ECG), have been used for the investigation of heart rate dynamics by measuring the wave-like signals generated in the heart. These signals are recorded over time and described by the term 'heart rate variability' (HRV). The heart rate variability is mainly controlled by the interplay between two branches of the autonomic nervous system (ANS), sympathetic and parasympathetic circuits [2]. The information from the analysis of the HRV normally may differ from one person to another, and depending on factors such as physiological conditions of the body and the types of activity performed by the person[3].

One of the clinical advantages of measuring HRV is that it can be used for the diagnosis of heart abnormalities in patients that may sometimes affect the individual performance of ADLs, and hence the HRV[4]. Examples of the physiological conditions that may affect personal performance and the HRV include: the chronic lung diseases and the heart problems, such as atrial fibrillation or congestive heart failure[4]. Previous research has revealed that the analysis of the HRV is very useful and cost-effective technique to investigate the effect of pathological as well as psychological conditions in human subjects[2, 5]. The power spectral analysis of heart rate variability by Ishbulatov, Gridnev [6], has shown a promising ability of the HRV to identify a certain subgroup of patients with higher sympathetic activation. The study by Rahman, Russell [7] suggested that there is a substantial negative relationship between HF power, RMSSD, and measures of LV systolic function in healthy individuals.Also the study of Barthélémy, Su [8]show that most patients with abnormal cardiac parasympathetic activity, such as in chronic heart failure, have reduced HRV as investigated by the electrocardiographic (ECG) analysis. In addition, the ECG measurement technique has been the cheapest diagnostic tool to quantify cardiac functioning profiles by screening heart rhythm of various groups of individuals in sports and patients in medical fields[9]. It can be used to diagnose in the heart's components and conduction systems [7]. Likewise, HRV analysis has been used to characterize normal physiological responses of the heart from a combination of other body systems, such as the respiratory and nervous systems due to postural change and simple exercise [2].

Various ECG analyses have shown the effectiveness with the ability to detect sensitive patterns of HRV response to both normal exercise and high work rates [4]. Other studies have shown that there have been problems during the assessment of HRV at higher work rates, with subsequent reduction in the variability or the physiological power bandwidths[2]. In most cases, there has been improvement on HRV status due to physical training that could be associated with an increased high frequency power and with either low frequency power reduction or increment. These findings have demonstrated consistency with the enhancement of vagal tone during faster post-exercise heart rate recovery times, and slower resting heart rates in individuals who have acquired aerobic training [7].

However, a limited number of studies have attempted to explain the heart rate variability in various states of body performance. The information concerning the variability of the heart rate in response to specific activities performed during daily living settings is still not well addressed. The present study aims to focus on this gap. In order to pursue this objective, it is desirable to quantify both HRV and a measure of the activities being performed during ADLs. Accelerometers provide various desirable features in monitoring human performance[10]. They can measure both static and dynamic motion of humans in a clinical setting and free-living environments. The accelerometer is also used as a standard device for measuring metabolic energy expenditure spent during the performance of physical activity[11]. The recent study of De Fazio, Mastronardi [12], has shown the success of a novel method to assess both physical activity and HRV simultaneously using the two devices, the ECG and the accelerometer. The findings showed that heart rate dynamics were closely tied to physical activity, as demonstrated by higher averages of both parameters. The information regarding the assessment ofadult human subjects using both wearable devices in a free-living environment is limited.

This study addresses a critical gap in the existing literature by using both the ECG and the accelerometer devices to assess HRV and the physical activities of daily living using normal adult subjects of the most active age group. While previous studies have explored HRV assessment in controlled laboratory or clinical settings, this research uniquely evaluates the heart rate variability (HRV) during various daily activities in free-living environmental conditions using ambulatory ECG and accelerometric measurements which are non-invasive and cost-effective.The findings aim to provide actionable data for occupational health, ergonomics, and personal wellness when evaluating HRV during Activities of Daily Living (ADLs).

Therefore, the objective of this study was to examine the HRV of human performance and to investigate the influence of environmental conditions on the HRV (especially music, speaking, and silence) during ADL performances. Theresults revealed information that supportsa useful guide for medical experts and safety stakeholders.Furthermore, the study would provide proper recommendations for people with certain health conditions in order to minimize health risks.

MATERIALS AND METHODS

Materials and Devices

In this study we used an ambulatory ECG monitoring device with three electrodes, Ambu white sensor, Reynolds medical/lifecard CF, Flash card and battery. Also we used the following devices: digital stopwatch/timer, digital mass balance, physician scale type, standiometer and tape. Others include: a standardized weights of 4kg/3kg, a backpack bag; 4 stacking shelves, a broom, skinfold callipers or Harpendencallipers, digital thermometer and hydrometer. In addition to that a PC and software packages (MS office 2010, MATLAB [R2011b], and IBM SPSS) were used to analyse ECGs and body composition during this study. The Accelerometers model X6-2min (18g), 16 resolution modes, were used for monitoring human motion while performing activities.

Study Design and Population

Eighteen healthy male subjects aged 18–45 participated in this study. ECG electrodes were placed on the chest, while a tri-axial accelerometer was positioned at the mid-back to record motion data. Subjects performed walking, walking while carrying a load, climbing and descending stairs, sweeping, and stacking shelves under three conditions: silence, conversation, and music. HRV analysis was performed using time- and frequency-domain methods, and power spectral density (PSD) was used to identify ULF and VLF bands.

Each subject was fitted with three ECG electrodes placed in a modified Lead II configuration on the chest, optimized for ambulatory monitoring. The accelerometer was affixed at the midline of the back, level with the T10 vertebra, using a hypoallergenic adhesive to minimize movement artifacts. Sampling rates for ECG and accelerometer were 1000 Hz and 100 Hz, respectively. All sensor data were synchronized and analyzed using custom MATLAB scripts and Kubios HRV Premium software.

Ethical Considerationsand Safety Approval

The study procedures were reviewed to ensure the quality of experimental measurements and the safety of subjects. Ethical approval was obtained from Swansea University in the College of Engineering, Applied Sports Technology Engineering and Medicine (A-STEM) research ethics committee before starting the study. All participants signed a written informed consent form at the time of data collection.

Heart rate variability (HRV) monitoring

Holter ECG monitoring (Pathfinder 700 workstation and Life card Digital ambulatory recorders; Spacelab Del Mar Reynolds Medical Ltd., UK), were used for the HRV assessment. The measurements were performed simultaneously with accelerometry in order to carry out cardiovascular monitoring of physiological parameters of the heart rate variability, for each subject with respect to 3 trials and stages of physical activity. These involved the application of recordings using a three-electrode ECG on the subject skin/body. The three ECG electrodes were placed on the subject's body chest forming an inverted 'V'; one electrode at the top and the other two at the lower opposite site within lowest part of chest region, between the two ribs' space. We fixed the ECG sensor electrodes, after cleaning the skin with an alcoholic tissue paper, to remove the dead tissue and we allowed the skin to dry for about 2minutes. This was important for improving electrical conductivity and the signal to noise ratio. The ECG records were taken from 9am to 1pm during working days of the week from Monday to Friday. These hours were chosen because the temperature and humidity ranges from the morning were relatively low and therefore could not affect the ECG signal because of sweating. Subjects were required to arrive at least 10 minutes so as to allow sufficient time for preparation of the experiment such as preparing the skin site for attachment of electrodes and time for signing the consent forms. To ensure good record of ECG data, we ensured that movement and other sources of artefacts were prevented or minimized, the electrodes leads were attached to the skin as shown in figure 5. We made loops with the electrodes lead cable under the tape in order to reduce the chance of dislodging the electrodes in case of unforeseen or sudden pull when the subjects were performing the ADLs.

Timing of the protocol when performing ADLs

A maximum time of about 39 minutes was allocated to complete the proposed experiment of ADLs that were selected from the most common daily routine tasks. The subjects were considerably instructed to perform these physical activities at their own or self-pace as they normally do in everyday life. The first aiders were available all the time along with the subject to monitor security and provide guidance to the subject where necessary, including controlling the timer (stop watch) to make sure that the prescribed protocol timeline is fully completed. However, the participation was completely voluntary and the subjects were free to withdraw from the study at any point.

Protocol for performing ADLs

Non-invasive physiological assessment of HRV and accelerometry monitoring were carried out during specified postural manoeuvres. These involved twelve stages which are listed in this section. These different postural changes and physical activity states allowed differential assessment of cardiac and autonomic nervous systems within 39 minutes. We repeated the previous ADL testing on two further days to complete three sets of data collection for all trial conditions (i.e. A=silence, B=with conversation and C=while listening to music). All the experimental testing was carried using available facilities as described below:

i) Stage 1, Seated: This was the initial stage of all trials testing carried inside the laboratory. After the preparation of the skin site of the subject and attaching of electrodes, as well as the setup of the ECG and the stopwatch; the subjects were allowed to sit on the chair while relaxed and breathing normally. Then the ECG and stopwatch were set on to start recording for three minutes.

ii) Stage 2, Walking: This was the second level after the initial stage, where the subjects were allowed to stand up and start walking for five minutes, at a self-moderate pace, in and outside the laboratory along the corridors, but within the building.

iii) Stage 3, Recovery 1 from walking: This involved three minutes recovery time from the walking stage. The subjects were again allowed to sit on the chair for resting, while we were also preparing for the next stage.

iv) Stage 4, Walking with load: At this level the subject was allowed to walk while carrying a load placed in a backpack bag of measured weight of approximately 4kg for an adult male and 3kg for female.

v) Stage 5, Recovery 2 from walking with load: This was the second recovery time from walking, but this time the subject was carrying a load. This also involved three minutes. The load was first taken away from the subject then allowed to sit on the chair.

vi) Stage 6, Climbing stairs: This was relatively the highest intensity physical activity where the subjects were asked to walk at moderate pace while climbing upstairs for three minutes. Most subjects climbed up to the 8 stairs in the Vivian tower building.

vii) Stage 7, Descending: The subjects were required to spend a maximum of three minutes to reached the highest stairs then allowed to turn up to descend downstairs in two minutes. In case of any remaining time, the subject was allowed to complete that time by walking in the lab.

viii) Stage 8, Recovery 3 from stairs: This level was completed for three minutes while the subject was sitting on the chair. After recovery time, the subject was allowed to stand up, ready to go, for the next stage.

ix) Stage 9, Sweeping: This activity was conducted in three minute, sweeping the floor using a broom. Sweeping process was carried out in random manner, i.e. there were neither specific direction nor sweeping style.

x) Stage 10, Recovery 4 from sweeping: When the subject completed sweeping the floor, they were again allowed for another resting time of three minutes while seated on the chair available at the nearby place.

xi) Stage 11, Stacking: This level spent three minutes only. The process involved lifting up and down the load on the shelves with a known weight of 4kg for male and 3kg for female. The subjects were required to lift the load (in the bag) and stack it on from one shelf to another. They were asked to start with the lowest to the highest possible shelves and without jumping or skipping any shelf. There were four shelves 206cm tall. The gap between one shelf and another was 48cm, whereas the distance from the ground to the first shelf was 51cm. The majority of volunteers were able to stack up to the third shelf; very few reached the last shelf. There no specific style of stacking, every individual had his/her own stacking pace.

xii) Stage 12, recovery 5 from stacking: This was the last stage and recovery time from stacking. It also spent three minutes while the subject was seated on the chair. After this final resting time, the ECG was allowed to record a few minutes approximately 20 seconds to complete any incomplete signal, then we stopped it to mark the end of testing. Finally, the equipment were removed from the subject’s body and repacked ready for the next session. The temperature and humidity were recorded at the beginning and at the end of testing.

DATA COLLECTION AND DATA ANALYSIS TECHNIQUES

Data collection

The ECG signal records, including the R-R intervals were recorded for a duration of minimum 39 minutes according to the protocol (Reynolds Medical Lifecard CF or Flash card) at an accuracy 1ms and saved on a computer for further analysis with Welch Periodogram and Matlab software (R2011b) [student version]. The R-R transducer was attached to the subject through the three dermal ECG electrodes; one was placed on the sternum and the other two on the left sides below the chest. Then the hardware setup of the ECG 100C amplifier was set at normal mode, high gain of 1000 sampling rate, 35Hz filter LPN, and 0.5Hz filter HP. The accelerometer was used to monitor body movement during performance of physical activity by collecting data counts in all three dimensions. The data from the accelerometer were used to calculate body acceleration the subjects.

Data Analysis Techniques

Data processing of the ECG recordings was split into segments of beats. The segments that contained artefacts and noises were removed. The quality of R-R data were assessed through the application of the HRV software basically to identify any signal distortions that might have been caused by various noises or artefacts. This facilitated to remove large broadband point artefacts from the R-R data before we carried out further analysis. Less than 1% of R-R intervals were corrected for every subject. Re-sampling of the non-uniform spaced R-R interval data were carried out by using a sampling frequency prior the next step for analysis of the data.

Time and frequency domain analyses were carried out considering that all undesirable data counts were eliminated. Only ECG data of twelve subjects who completed all three trials were considered for further analysis. Through data inspection, the R-R intervals were edited in each subject. The deletion method was used to eliminate the edited R-R and they were replaced with the normal R-R. The average data of the heart rate (HR) and square difference between R-R intervals (SDRR) and root mean square differences in successive R-R intervals (RMSSDRR) were applied to determine the time domain measures of HRV. We also averaged data of the frequency domain parameters including the low-frequency (LF) at (0.03-0.15Hz), high- frequency (HF) at (0.15-0.45Hz) and very low frequency (VLF) which were computed from the specified blocks of frequency beats.

The VLF (0-0.03 Hz) component was analysed in longer block of highest amplitude while considering any fluctuating interaction in the lower frequency band with VLF power physical activity, was also fully investigated. Total power was analysed as the area under the curve of the power-frequency spectrum. The following figure shows an example of heart rate variability spectra from R-R data versus time plots from one of the data recorded in 39 minutes.

Statistical treatment were executed using tests for normality of the data to determine the use of parametric or non-parametric analysis methods between-activity and trials conditions. The normality check was carried out to all ten parameters to observe if there were normal distributions of the HRV data. Most raw data were not normalized (skewed) until when the raw data were converted into base ten logarithmic values. Only raw data for high and low frequency power were found normalized.

That implies that the normality schemes were achieved before the statistical analysis, and thus the parameters whose raw data initially produced normal distributions were not log transformed and were selected directly for final analyses. After the normality inspection of all other data was conducted using MATLAB software, followed by another statistical testing which was carried out later, through the SPSS software version 14.0 for Windows and Mac OS (IBM SPSS, Chicago, IL). For All analyses, the significance level less than 5% was regarded for the probability or statistical significance. Other analyses of HRV parameters, i.e. graphical method were analysed via MS Excel analysis using raw data and the average normal values.

RESULTS AND DISCUSSION

Physical characteristics of the subjects

Table 1 provides the basic characteristics of the subjects who participated fully in the study, i.e., subjects who completed successfully the protocol for three set trial conditions during HRV testing. During physical examination procedures, we did not identify any significant clinical abnormalities among the subjects. All the participants who volunteered for the ECG measurement had a normal, regular rhythm of the heart.

Table 1. Physical characteristics of the subjects

Variable	Mean values (n=18)
Age (years)	27.21±5.12
Body mass index (kg/m^2)	23.67±3.50
% Body fat	18.06±4.25

HRV Analysis: Stage Effects Summary of findings

This section summarizes the statistical results related to the effects of experimental stages on heart rate variability (HRV) parameters. The analysis was conducted using repeated-measures ANOVA via IBM SPSS (version 14), and included Mauchly's test of sphericity.

The analysis showed that no HRV parameter exhibited significant variation across the 12 stages (all p-values > 0.05). LF and HF again showed relatively higher sensitivity, though still within non-significant ranges. These findings support the robustness of HRV as a physiological measure under structured protocols and align with the conclusions from recent studies of [13], Laborde, Mosley [14] and Mosley and Laborde [15].

Table 2. Summary of HRV Parameter Statistics across Stages

HRV Parameter	F-value	p-value	Partial Eta Squared
RR	1.600	0.210	0.086
HR	1.500	0.225	0.086
SDRR	1.550	0.218	0.086
RMSSD	1.520	0.220	0.086
LF	1.640	0.205	0.086
HF	1.610	0.212	0.086
VLF	1.490	0.230	0.086
TF	1.530	0.215	0.086
HFn	1.510	0.223	0.086
LFn	1.420	0.240	0.086
PRRTot	1.514	0.235	0.084

Pairwise Comparisons and Trial Interaction Summary of findings

This section summarizes the pairwise comparisons conducted on RR intervals and other HRV parameters across different trials and protocol stages. The analysis focused on identifying significant differences in HRV metrics between experimental stages and trial conditions using post hoc testing and ANOVA-based methods. The findings show that RR interval comparisons revealed significant differences for stage 1 with most other stages ($p < 0.05$), excluding stages 3 and 5, which acted as recovery phases and showed no statistical difference. Pairwise comparisons among Trials A, B, and C showed no significant differences across HRV parameters. The RR and HR values between Trial A and B showed marginal significance ($p = 0.05$), while A vs. C ($p = 0.336$) and B vs. C ($p = 0.572$) showed no statistical significance. Other HRV metrics reflected similar non-significant differences across trial comparisons.

The observed stability in HRV parameters across different trials and stages aligns with findings from recent research. Studies have shown that under moderately stressful or emotionally neutral conditions, HRV remains relatively consistent, reflecting stable autonomic regulation. Additionally, Laborde, Mosley [14]emphasized that HRV is sensitive primarily to significant cognitive or emotional load changes, which were not markedly present in the current protocol. Georgieva-Tsaneva, Gospodinova [5] further supported the view that HRV remains robust across controlled experimental variations, particularly when physiological biofeedback mechanisms are not actively disrupted.

Table 3. Summary of Pairwise Comparison Results

Comparison	p-value	Significance
Stage 1 vs Others	< 0.05	Significant (except vs Stages 3 & 5)
Stage 3 vs Stage 5	> 0.05	Not Significant
Trial A vs Trial B	0.05	Marginally Significant
Trial B vs Trial C	0.572	Not Significant
Trial A vs Trial C	0.336	Not Significant

HRV Analysis: Graphical Method

This section summarizes a detailed analysis of HRV variables across all three experimental trials and 12 stages of activities of daily living (ADLs) was conducted using raw and normalized data processed via Microsoft Excel. Line plot visualizations of the RR interval showed consistent patterns across all trials (A: silence, B: conversation, and C: music), indicating that individual subjects exhibited similar trends to the group averages as shown in Figure 1. Comparable trends were observed in other HRV parameters, implying no statistically meaningful differences in autonomic responses between trials or across ADL stages.

In contrast, heart rate (HR) data in Figure 2 exhibited more noticeable fluctuations, reflecting physiological responses to varying activity intensities. These fluctuations suggest that HR rises proportionally with physical demand, likely due to increased cardiovascular effort needed to supply oxygenated blood to active muscles. The average HR across all trials was 83.13 ± 5.98 bpm. Breakdown by trial showed Trial A (silence) at 80.6 ± 9.3 bpm, Trial B (conversation) at 82.0 ± 9.8 bpm, and Trial C (music) at 86.4 ± 11.0 bpm. Stair climbing elicited the highest HR values, while sweeping had the lowest. Walking and sweeping produced closely matched HR responses, suggesting both fall under similar intensity categories. Individual subject HR patterns largely aligned with group means, with most falling between 50 and 100 bpm during moderate tasks such as walking and stacking, while more intense activities like stair climbing led to HR increases up to 140 bpm. These findings are consistent with previous research, which defines typical HR ranges for healthy individuals during rest or light exertion as 60 to 100 bpm [5].

Integration of electrocardiogram (ECG) and accelerometer data also highlighted a positive correlation between HR and body movement. Specifically, HR increased proportionally with body acceleration (Figure 4), while RR intervals showed an inverse relationship with acceleration (Figure 3), underscoring the interplay between physical workload and autonomic cardiovascular control [4].

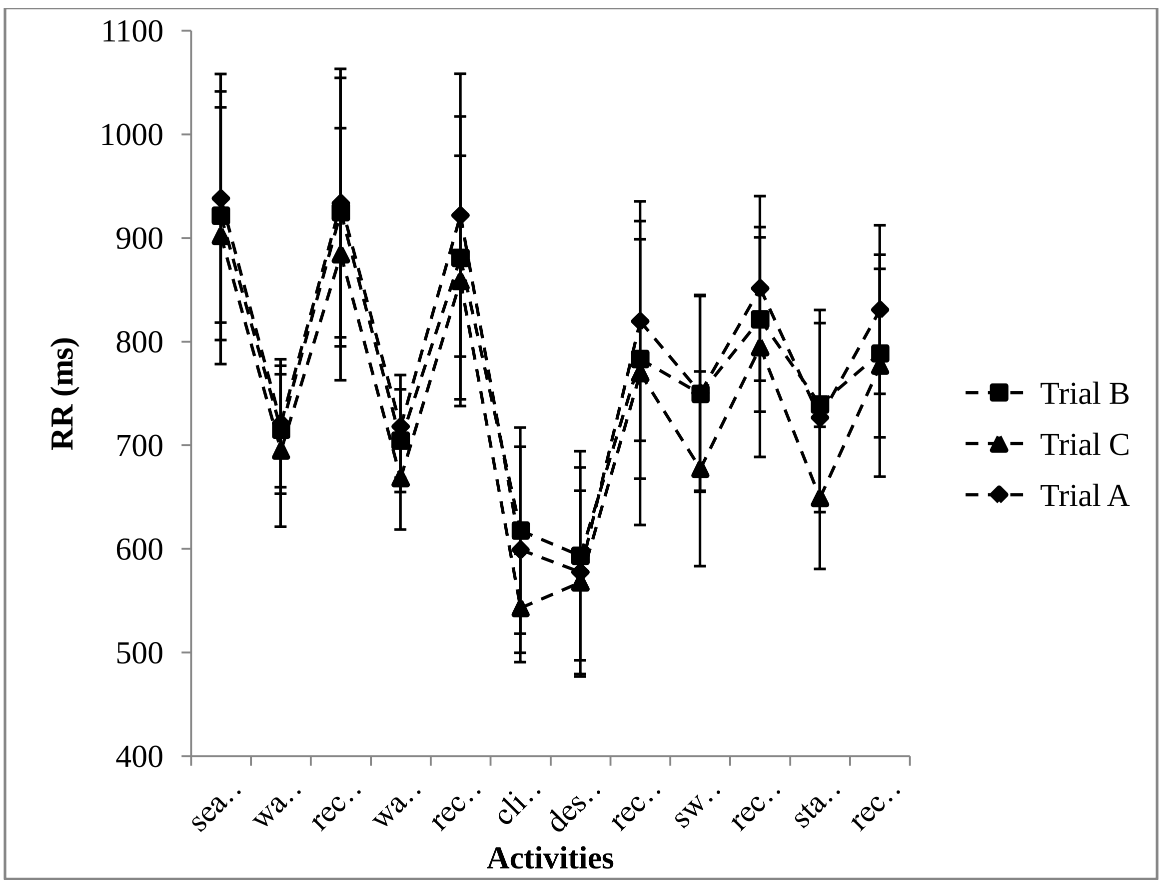

Figure 1. RR line plots for Trials A, B and C illustrating similar trends of the RR intervals.

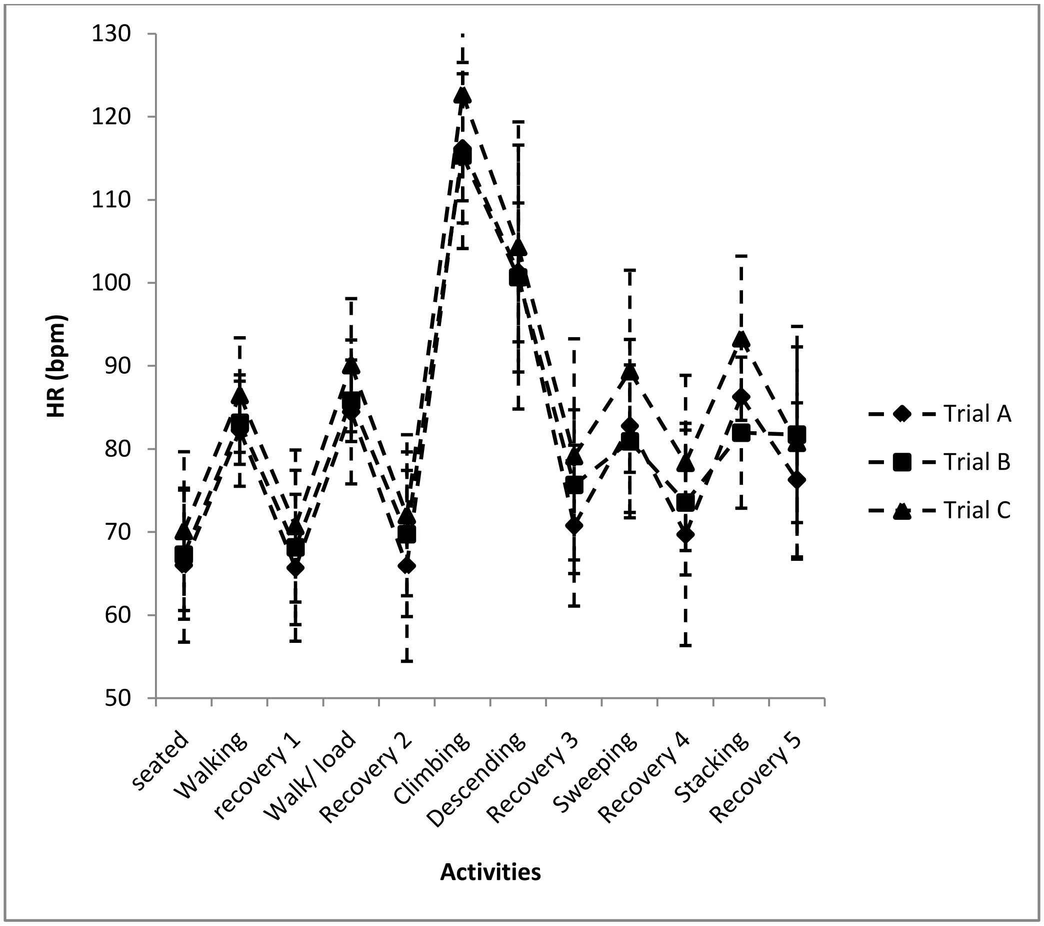

Figure. 2: HR Line-Plots Showing Three Trials To Demonstrate The Same Trends

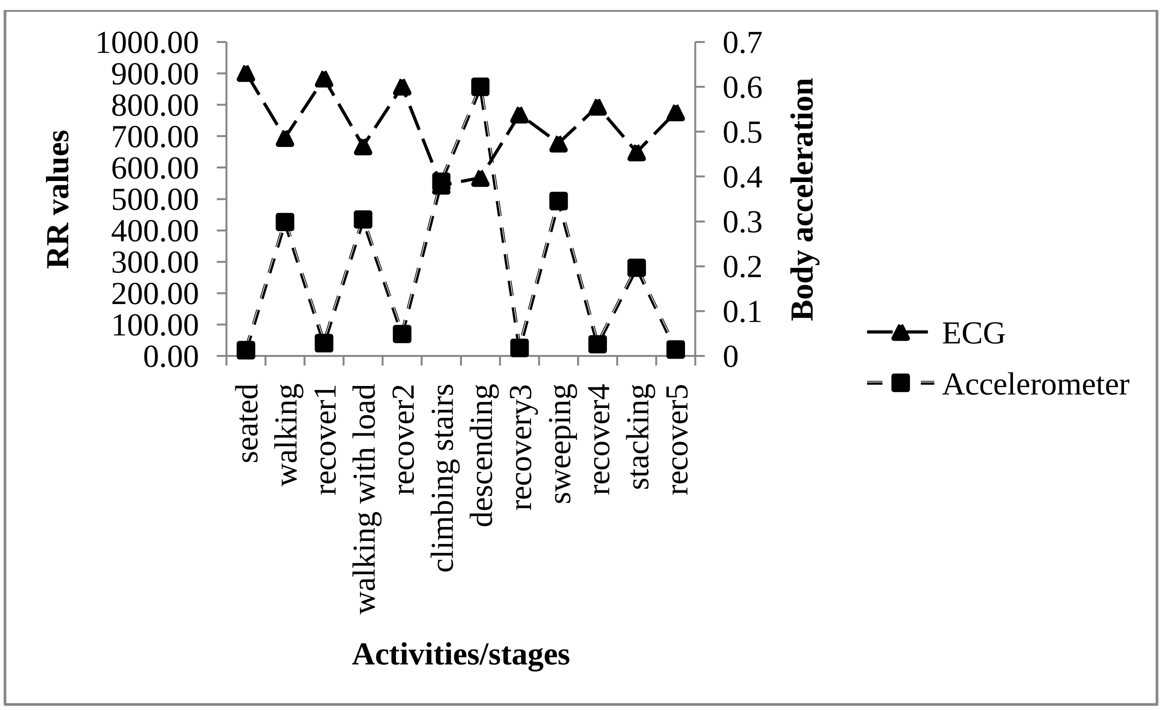

Figure 3: The Line Plots Showing Integration Of ECG (RR) & Accelerometer's Data (The Body Acceleration)

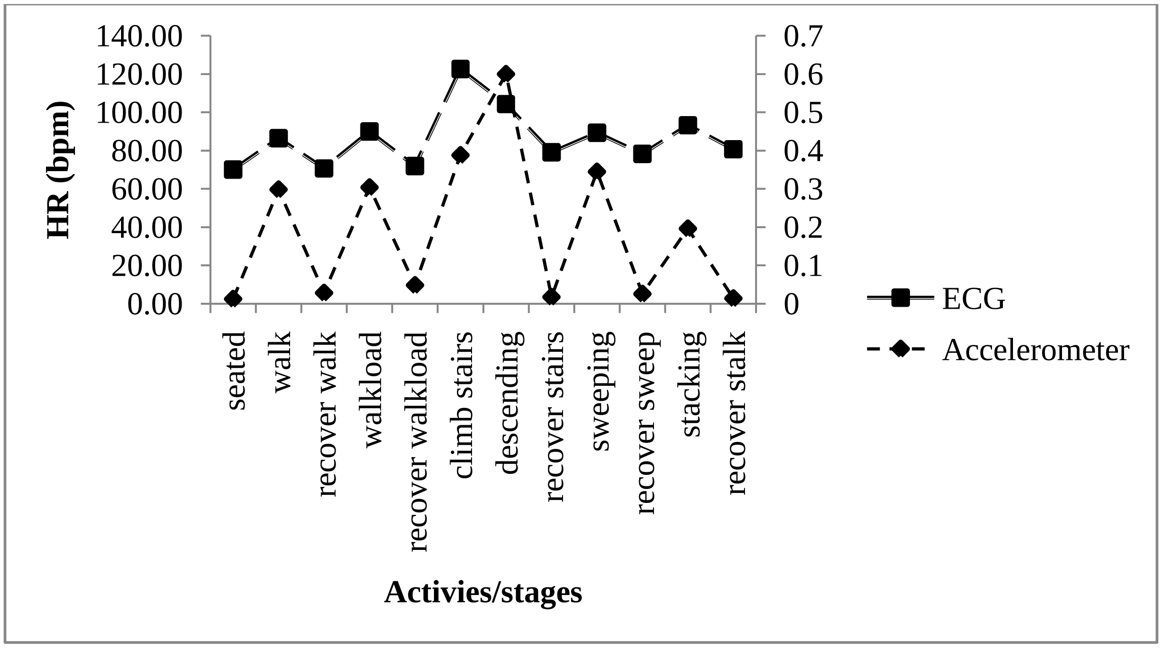

Figure 4: The Line Plots Showing The Trend Of Integration Of ECG (HR) &Accelerometer's Data Body Acceleration

CONCLUSION

In conclusion, the study on HRV responses across three trial conditions and selected twelve ADL stages reveals a stable autonomic pattern under varying acoustic situations, with minimal influence on HRV parameters such as RR, HR, and frequency domain metrics. This stability supports the notion that under emotionally neutral or mildly stimulating conditions, the autonomic nervous system maintains homeostasis regardless of external auditory input. In contrast, heart rate data demonstrated sensitivity to changes in physical exertion, with higher activity concentrations such as stair climbing stimulating corresponding increases in Heart Rate. These physiological patterns align closely with findings from prior research regarding normal HR responses to daily activities in healthy individuals[2, 7].Furthermore, the integration of ECG and accelerometer data emphasizes a clear correlation between movement and cardiovascular response, indicating that HR increases with physical activity while RR intervals decrease. These results reinforce the reliability of using HRV as a practical biomarker for assessing physiological demand during ADLs. Ultimately, these findings contribute to a growing body of evidence that supports the role of HRV monitoring in assessing workload and cardiovascular stability in everyday environments.

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