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ASSESSMENT OF PHYSIOLOGICAL AND MUSCULOSKELETAL RISKS AMONG BICYCLE RIDERS DURING RIDING AT DIFFERENT POSTURES

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Abstract
Cycling is one of the most popular and economic way of transport. It requires rider to bend forward and to maintain the forward flexion posture throughout the ride. This posture along with repeated motions of body segments during the ride leads to the risk of musculoskeletal disorders. The aim of this study was to analyze the physiological and musculoskeletal risks experienced among bicycle riders, when cycling is done at different postures. The study was done using a road bike, with riders adopting three postures such as tops, hoods and drops. The study includes experimentation using heart rate monitor to assess physiological risk. Digital human models of bicycle rider postures were developed for the assessment of musculoskeletal risk. Results indicated that tops posture has the least and drops posture has the highest severity of physiological risk among the riders. Musculoskeletal risk identified with rapid upper limb assessment (RULA) score of different postures also supports these findings. From the individual RULA scores, it was observed that trunk, neck and lower arm were found to be the critical segments. The physiological and musculoskeletal risk among bicycle riders can be reduced by adapting tops posture that contributes lesser risk in these critical segments.

Keywords: Ergonomics, musculoskeletal risks, physiological risks, cycling, posture analysis.

1. Introduction

Cycling is one of the popular sports in the world and it is also used as effective equipment towards fitness. Cycling requires a rider to lean forward and maintain this forward flexion posture for the entire ride [1]. Physiological risks and musculoskeletal risks are considered as the biggest problems faced by the cyclists in the world. Physiological risks can be assessed with blood lactate concentration method, electromyography (EMG) method and heart rate variability (HRV) approach. Among these methods HRV is popularly used for physiological assessment in literature [2-3]. HRV is defined as the variation in time interval between consecutive heartbeats [4]. HRV in time and frequency domain measures can be used to quantify the measures of central nervous system (CNS). Time domain measures can be used to quantify the sympathetic and parasympathetic activities of CNS. Frequency domain measures can be used to quantify the overall mental fatigue. HRV indices would give a direct measure of effort put during a physical activity. Musculoskeletal risks refer to musculoskeletal disorders (MSDs), which can be considered as injuries or disorders that impair the movement of human body or musculoskeletal system [5-6]. Among the various MSDs, overuse injuries have the highest prevalence, which may lead to frequent interruption of cycling training. These overuse injuries in cyclists are mainly caused by repeated motions, over stress and awkward postures of the rider. Studies indicated that the intensity of stress experienced by the cyclist varies with the different postures [7]. So the posture adapted by the cyclists has a major impact in developing MSDs among them. In order to analyze the musculoskeletal risk associated with different postures, literature explains the usage of digital human modeling (DHM) [8-9] and its integration with rapid upper limb assessment (RULA) method [10-13]. In this study, DHM integrated with RULA and HRV analysis were adopted to identify musculoskeletal and physiological risks respectively. Detailed methodology adapted for the study is explained in the following section.

2. Method

The methodology consists of two parts such as HRV analysis and DHM (Figure 1). In order to conduct HRV analysis an experimental setup was developed. With help of heart rate monitor device HRV data of participants were collected and analyzed using Polar ProTrainer5™ software. In DHM part, computer aided design (CAD) model of bicycle used in the experiment (road bike) was developed and exported to Tecnomatix Jack software. Based on database available in the software and data collected from participants, digital manikins were created. Afterwards, virtual posture analysis was done for different postures using RULA method. Based on the analysis of HRV and DHM, risks associated with different postures were identified and suggestions for risk reduction were incorporated.

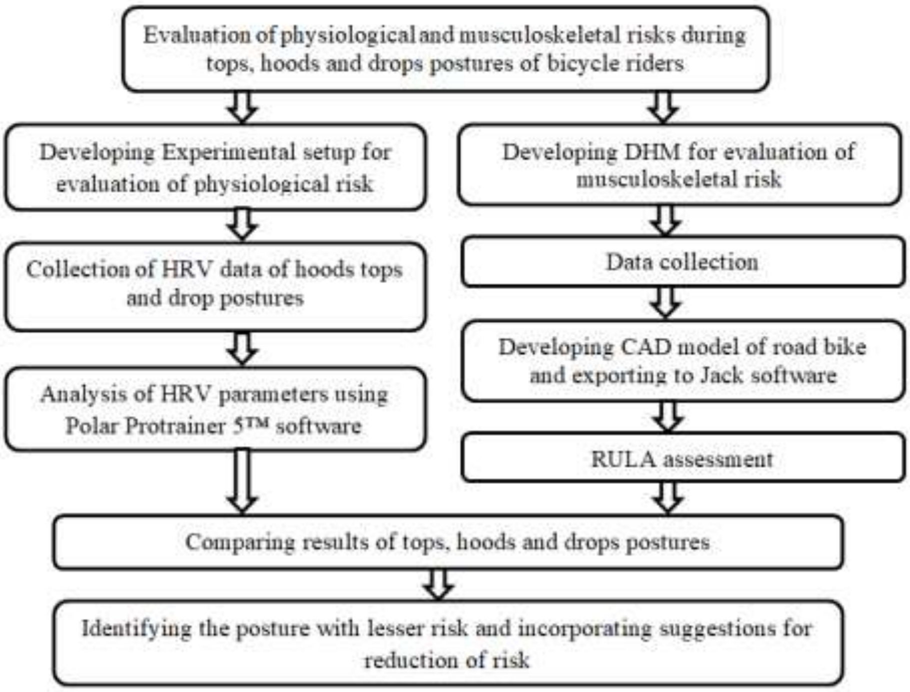

Figure 1: Methodology

2.1 Participants

Convenient sampling was used for data collection in this study. Based on Cochran's formula, sample size was fixed as 58 participants, which provides a confidence level of 90% and 10% margin of error [14]. The participants were screened with an experience of more than one year in regular cycling and body mass index (BMI) in the range of 18.5-23 kg/m2 [15]. Out of the 58 participants, 40 participants meet the above mentioned criterions and they were selected for the study and others were screened out. All the participants submitted a written consent before participating in the study. Details regarding years of experience in cycling, height, weight and BMI of participants were collected.

2.2 Experiment setup

The equipment for experiment includes Polar heart rate monitor (Polar RS800CX), BTwin cycle computer, road bike and Polar ProTrainer5™ software. The road bike has option of two frame sizes, for accommodating large (95th percentile) as well as average (50th percentile) population. The Polar heart rate monitor includes a heart rate sensor unit (Wear link & transmitter) and a wrist unit (Polar training computer). The sensor unit is fixed on the body of the participant with a chest belt (Figure 2). This device records HRV data and transmits it to wrist unit. The wrist unit stores the data received from the sensor. Later, this data is transferred to Polar ProTrainer5™ software for further analysis. The BTwin cycle computer fixed on the road bike measures the speed of the rider.

HRV data collection and study protocol

The study was conducted at Trivandrum city of Kerala state in India. The route for travel was fixed as from "Kulathoor Junction" to "Kovalam Junction" in National highway road at Trivandrum. The route consists of level ground road as well as roads with uphill and downhill. The time frame selected for conducting the study was from 8 p.m. onwards, as the traffic is minimal. A practice session was provided for the participants on one day before the actual experimental day. There was a warm up session of fifteen minutes conducted half an hour before the experiment trial heart rate of each participant is recorded at beginning of experiment. Aubert et al. [16] recommends minimum HRV recording time of 10 minutes. The comparisons of HRV recordings requires equal duration [17]. As per these recommendations the study protocol was formulated with one hour continuous reading for all the trials. The experimental trials consist of participants doing cycling on the smooth tarmac road for one hour continuously without any rest period by maintaining a specific posture. One of the authors also accompanied the participants to ensure this experiment protocol. The experiment trials were conducted for all three postures for each participant. At end of each ride physiological data from heart rate monitor, distance travelled and average speeds were recorded. After each experimental trial, the data recorded on the wrist unit of heart rate monitor was exported to the Polar ProTrainer5™ software.

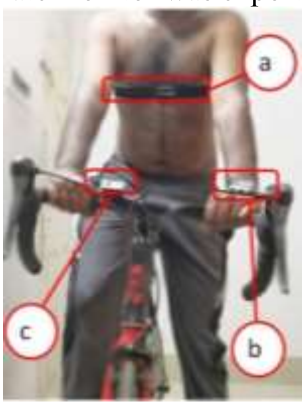

Figure 2. Experiment setup: (a) Polar heart rate sensor unit, (b) Polar training computer (wrist unit), (c) BTwin cycle computer

2.4 HRV analysis

The Polar heart rate monitor was used to record all the HRV data from the participants in experimental trials with duration of one hour. This one hour duration was then split in to six equal segments, each of duration of ten minutes. Each segment was then analyzed. Time domain measures such as standard deviation of normal to normal intervals (SDNN), root mean square of successive differences between normal heart beats (RMSSD) values and frequency domain measure of low frequency to high frequency ratio (LF/HF) values were obtained with help of the Polar ProTrainer5™ software.

2.5 Digital Human Modeling (DHM)

In DHM part of the study as a first step, design specifications of road bike were collected. In order to develop a virtual cycling environment, CAD model of the road bike was constructed from the collected specifications. Subsequently, human manikin was generated with Indian population database in Jack software based on height and weight of the participants. This CAD model of the road bike was then exported to Jack software and integrated it with the human manikin to carry out risk assessment.

2.6 Risk assessment using RULA

RULA is a tool that is widely used in ergonomic studies and available with Jack software. This tool helps in identifying musculoskeletal risks associated with a workplace environment [18]. The risk factors considered by this method are number of movements, static muscle work, working posture and force. The body segments considered in this method were upper arm, fore arm, wrist, neck and trunk.

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There are a range of scores designated to each of the body segments, based on the severity of risk. RULA method provides a final score in 1 to 7 that indicates the severity of musculoskeletal risk. The integrated digital model of manikin and road bike was used for determining RULA score for different cycling postures. The manikins were selected to represent the populations based on road bike design options (95th and 50th percentiles) and the sample population (75th percentile) under study.

3. Results

The HRV indices, digital human modeling and postural evaluation are carried out the results are tabulated and analysed in this section.

3.1 HRV indices

From the HRV data collected from participants, SDNN, RMSSD and LF/HF ratio were extracted using Polar ProTrainer5™ software. Time related variations of these indices are shown in Figure 3.
From the plots, it is evident that the average heart rate (AHR) for drops posture was always greater than other two postures for the entire duration of the ride. The plots of RMSSD and SDNN indicate lower values of the drops posture than the values of tops and hoods postures. The rider in drops posture is in a strained posture than other two. A small variation is only found in RMSSD and SDNN values of tops and hoods postures. From the plot of LF/HF, it is observed that there is no much difference between LH/HF in different postures.

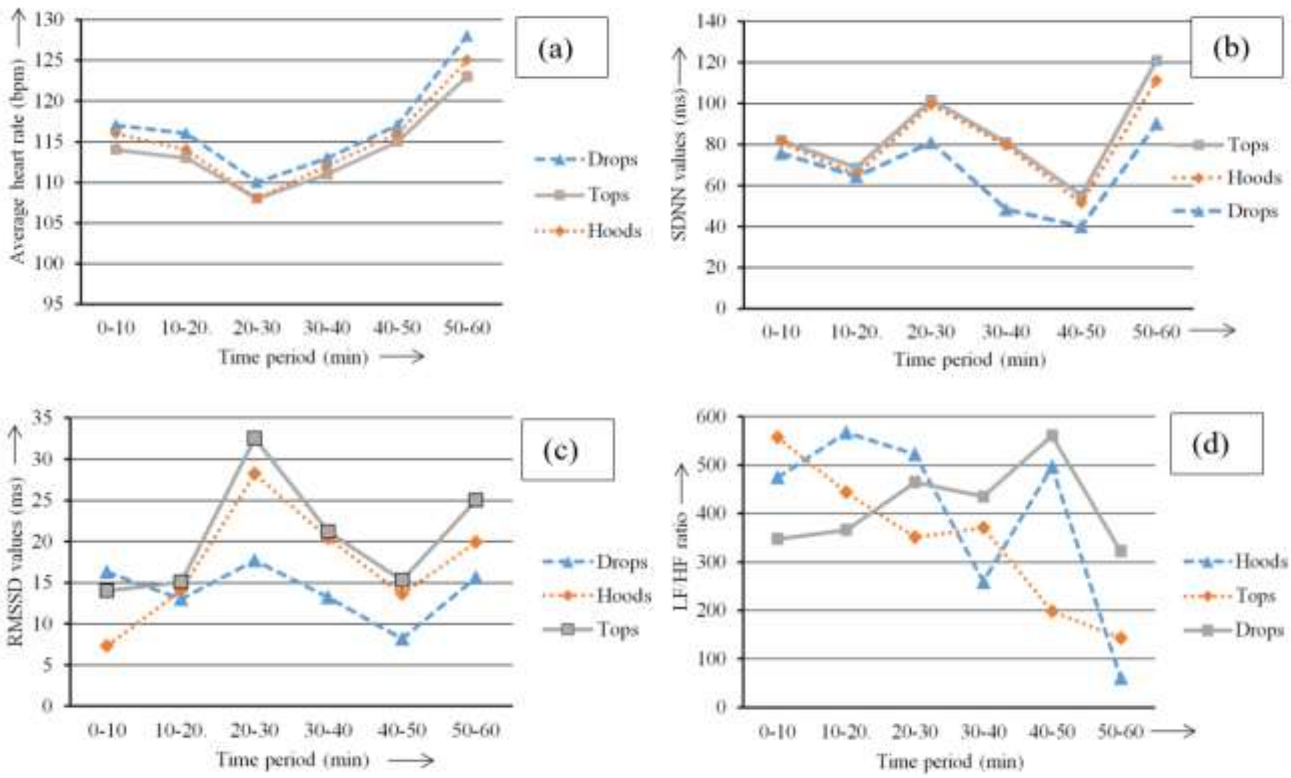

Figure 3. Variation in HRV parameters (a), Average heart rate (b), SDNN values c), RMSSD values and (d), LF/HF ratio

3.2 Digital Human Modeling (DHM)

In DHM, 95th, 75th and 50th percentile manikins were developed in the Jack software. The manikin developed for 50th percentile population in drops, tops and hoods postures are shown in Figure 4. The postural evaluation was carried out for all the three posture with 95th, 75th and 50th percentile manikins. The postural evaluation of these nine postures was carried out using the RULA method.

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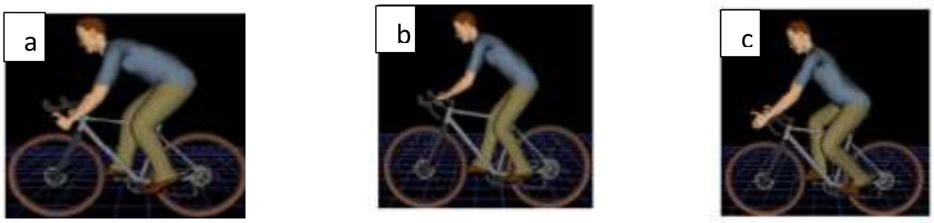

Figure 4. 50th percentile male manikin for (a) drops, (b) tops and (c) hoods postures (snapshots)

3.3 Postural Evaluation

The final RULA scores of the nine postures are shown in the Figure 5. From the figure, it is clear that severity of physiological risk is higher (score of 7) in 95th, 75th and 50th percentiles of drops posture. The guidelines of this score suggest that an investigation and changes in posture required soon. Maintaining drops posture for a long period of time may result in pain, fatigue and MSDs in upper body segments of the rider. Considering the severity of risk, hoods posture comes second to drops posture. The final scores of 95th and 75th percentile hoods posture is 5 and that of 50th percentile is 6, which indicates that 50th percentile hoods posture is more riskier than other two.

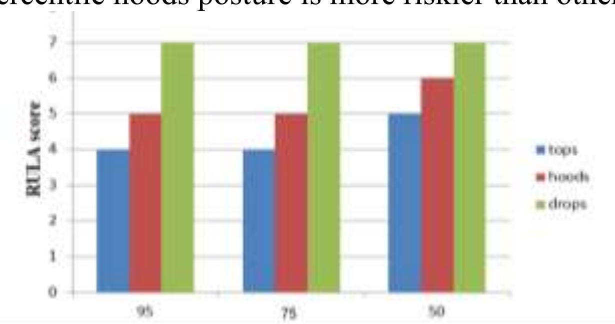

Figure 5. Final RULA score

Even though there is difference in final scores, investigation and changes in posture are required soon in case of hoods posture as per guidelines. Cyclists should avoid maintaining hoods posture for a long period of time. Among the three riding postures the tops posture is having the least severity of risk. The final scores of 95th and 75th percentile tops posture is 4 and that of 50th percentile tops posture is 5. In the case of 95th and 75th percentile tops postures action level requires is investigation and some changes required in the posture. This action level is not required immediately. The individual RULA scores for different body segments are shown in Table 1. From the table, it is observed that the individual RULA scores for different body segments were similar except in neck and trunk body segments. The critical areas of body segment are lower arm, trunk and neck. The score for lower arm is 3 in every posture; the severity of risk is high in lower arm immediate attention is needed in this segment. The individual RULA score for neck in all postures is 4, which indicates a high severity of risk. Immediate attention and changes are required soon in this segment. The individual RULA score for trunk in all postures of drops and 50th percentile manikin of hoods posture is 4, this indicates that the severity of risk in this segment is high and immediate action is required to reduce the risk severity. Also the RULA score for 75th, 95th percentile manikin of hoods posture and 50th percentile manikin of tops posture is 3, which indicates that severity of risk is high in this region and immediate action is required to improve it.

Table 1. Final RULA score

Body Segments	RULA Score for 50th , 75th and 95th percentile population in different postures								
	Tops			Hoods			Drops		
	50th	75th	95th	50th	75th	95th	50th	75th	95th

Upper arm	4	4	4	4	4	4	4	4	4
Lower Arm	3	3	3	3	3	3	3	3	3
Wrist	2	2	2	3	3	3	2	2	2
Wrist Twist	2	2	2	2	2	2	2	2	2
Neck	4	4	4	4	4	4	4	4	4
Trunk	3	2	2	4	3	3	4	4	4

4. Discussions

Analysing the SDNN and RMSSD in the results (Figure 3), it was observed that RMSSD and SDNN values of drops posture were lower than the other two postures in all time intervals. The lower values of RMSSD and SDNN of drops posture indicate that the rider in this had experienced lot more effort during cycling than other two postures, which points out that the drops posture is much more strained posture than others [4, 19-20]. It was observed that AHR of riders in drops posture was greater than other two postures in all time intervals which validate the above points. From the above points it can be understood that the physiological risk is higher in drops posture. From plots it was observed that there was no much difference between the values of AHR, SDNN and RMSSD between tops and hoods posture. This indicates the physiological risk between tops and hoods were almost similar. Also it is observed that there wasn't much difference in the values of LF/HF ratio between the three postures, which indicates that the mental fatigue among the different posture were almost similar. During the time interval of 20-30 minutes, a reduction in AHR with corresponding increase in SDNN and RMSSD was observed. The reduction in AHR can be attributed to the less effort in cycling on level ground road during this time interval, while the riding route consists of uphill and downhill segments as well. The inverse relation of AHR with time domain parameters of HRV is also evident from literature [20].

The final RULA scores of tops (95th, 75th, 50th), hoods (95th, 75th, 50th) and drops (95th, 75th, 50th) postures were (4, 4, 5), (5, 5, 6) and (7, 7, 7) respectively. These values show that tops posture has the lowest value of final RULA score among all three postures in all percentile values, which indicates that tops has the least severity of musculoskeletal risk among the three postures, but still some changes are required in the posture to reduce the risk. The drops posture has the highest of value of final RULA score among the postures in all percentiles male manikins, which indicates that drops posture has highest severity of musculoskeletal risk among the three postures and an immediate action is required to reduce the risk. The final RULA scores of hoods posture is in between the tops and drops postures, which indicates that the severity of musculoskeletal risk in hoods posture is in between tops and drops posture. Changes are required in the hoods posture soon to reduce the risk. Many literatures has indicated that a posture is acceptable when the RULA score is less than or equal to 3, which indicates all the postures requires changes, but the time frame within which it is to be done is different for three postures [10-13]. In drops posture changes are required immediately, in hoods postures the changes are required soon and in tops posture the changes are to be done in the near future. The individual RULA score for neck in all postures was 4 which indicated a very high severity of risk; this is because individual RULA score of neck is 4 irrespective of any degree of backward flexion of neck. The individual RULA score of lower arm is 3 irrespective of the postures; this is because of lack of lower arm support. The individual score for trunk in drops (95th, 75th and 50th) and hoods (50th) posture indicates high severity of risk. The final RULA score of a posture is based on the individual score obtained for different body segments. In order to improve the final RULA score the individual RULA score must be improved. Here all the postures require changes in order to improve the final RULA score, this can be achieved by improving the individual RULA score of the critical segments such lower arm, neck and trunk.

5. Conclusions

In order to conduct the evaluation of physiological and musculoskeletal risks of cyclists during tops, drops and hoods postures, HRV analysis and DHM were used. From the time domain indices of HRV such as RMSSD and SDNN, it was understood that the these values for drops posture was lower than other two postures, indicating that the rider in drops posture experienced higher physiological strain than others . There wasn't much difference found between RMSSD and SDNN values of tops and hoods posture. Also tops posture was found to have least severity of physiological risk. From the final RULA scores of different postures it was found that the drops posture has the highest RULA score followed by hoods and tops postures. This means that the drops posture has the highest severity of risk followed by hoods and tops posture. Investigation and modifications in the posture was required immediately in case of drops and hoods posture, whereas in tops posture the severity of risk was less compared to other postures, so some changes are required in that posture. From the individual RULA scores obtained, it was found that neck; trunk and lower arm were the critical body segments. The severity of risk was high in these body segments. Mainly the RULA scores neck in all postures were very high indicating high severity of risk in that area, demanding immediate action to be taken. Also RULA scores of trunk in drops and hoods posture were high demanding immediate action to be taken to reduce it. The final RULA score of a posture is based on the individual score obtained for different body segments. In order to improve the final RULA score the individual RULA score of body segments must be reduced. Here all the postures require changes irrespective of the RULA score. In order to improve the final RULA score, the individual RULA score of the critical segments such as lower arm, neck and trunk must be reduced. This indicates future scope of redesigning the postures. The neck flexion and forward flexion of trunk in all postures can be modified by adjusting the handle bar height. The risk in lower arm can be reduced by providing adequate arm support. Road gradients of the route used in experimental trials are not synchronised with HRV data collected in this study. It can be included in future studies to obtain more insight about the variation of HRV among bicycle riders with different gradients of road.

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