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Epidemiological root cause analysis of noise and physio-psycho impacts related to motorcycle road accidents

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Abstract: Background: An epidemiological increase in the trend of motorcycle road accidents requires an in depth investigation, which may arise due to malfunctioning of motorcycle, riders or environmental characteristics motorcycle accidents as responsible for morbidity and mortality. Objectives: This root because analysis aimed at highlighting the detrimental factors associated with chronic high noise exposure that may lead to physiological and psychological malfunctioning and to create a model of the association between noises induced adverse health effects and its relation to motorcycle road accidents. Results: A root cause model of association revealed the interactive association of noise with physiological and psychological malfunctioning at various noise levels and from different sources of noise ($p= <0.05$). This noise levels are directly associated with malfunctions, while linking indirect associations with one another. Conclusions: Such prolonged disparities of physical and mental health has more adverse effects than acute exposures on health, which increased its probability of indulging an individual to higher risk of road accidents. Among the gaps identified for motorcyclist morbidity and mortality included a need to investigate environmental noise sources among the root causes. In root cause analysis it can be assumed that physiological and physiological malfunction can play a vital role in the causation of road accidents.

Key words: Motorcycle accidents; Physiological health; Psychological health; Noise

1. Introduction

Motorcyclists are considered to be the most vulnerable road users with ratio of fatalities nearly 3, 6 and 50 times higher than a car, pedestrian and bus passenger respectively (Abdul Manan and Várhelyi, 2012). World Health Organization (2013) reported 58% road fatalities out of the 47% registered motorcyclists globally in 2013(WHO, 2013). According to Road Traffic Injury report (RTI) by WHO (2013), road traffic injury is placed in ninth position on the leading cause of death chart and is regarded as a burden of disease, they further predicted that it might increment to become the fifth leading cause of death by 2030. Furthermore, while defining a strategy for road traffic injury prevention by WHO, it was predicted that globally the number of road traffic accidents might increase to 8.4 million by 2020 (Peden et al., 2001). This overwhelming increase of motorcyclist's road fatalities and injuries in either developed or developing countries will remain the major contributor to the road fatalities (Hussain et al., 2005).

Apart from being the cheapest, easiest, and convenient mode of transport, motorcycles are not only hazardous/ dangerous vehicles but also a contributing source of noise pollution. There is a direct cumulative effect of vehicle's noise, wind noise, and traffic noise on the motorcyclist. The noise level inside the helmet at 60 km/h is 90 dBA, which increases with speed and reaches around 110 dBA at 160 km/h (Mccombe, 2003; Van et al., 1981). The daily noise exposure on riders exceeds 90 dBA (ISVR Consulting University of Southampton, 2014) constituting chronic high noise which needs further investigation for its effects on riders in regard to their travelling duration.

This study identified the associated root cause of motor cycle accidents among motorcyclists arising from noise while riding motorcycles.

2. Root cause analysis

The root cause analysis (RCA) was adapted from Siti et al. (2015). A new probability model was proposed for noise induced psycho-physio disparities for motorcycle accidents. Five steps in RCA include:
i). Identifying of issue arises,
ii). Opening and closing of investigation paper,
(iii). Controls of hazards and risks,
(iv). Maintenance of applied controls or recommendations;
(v). Review of the root cause analysis of risk of injuries.

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2.1. Identifying of issue arises

The most common documented adverse health effects of noise are categorized into hearing impairments, cardiovascular diseases, hypertension and impairments in mental health such as task performance, attention, anxiety, depression, and fatigue and annoyance reactions. World Health Organization (WHO) regarded environmental noise as a stressor or a threat to public health. The stress response remains active as long as noise persists and increases the heart rate, blood pressure, and breathing (Goines and Hagler, 2007). Noise up to the level of 90 dBA is sufficient for activating the stress response (Evans et al., 2001), that is the glucocorticoid hormone cortisol (Lupien et al., 2005). The increase in glucocorticoid hormone cortisol has adverse physiological and psychological reactions, which includes increased blood pressure, hypertension, annoyance, memory deficits, fatigue and aggression, which over the time leads to more chronic diseases (Stansfeld and Matheson, 2003). Since cortisol activates on every onset of high noise level, which in the long term leads to deteriorating physical and psychological health impact on the exposed individual, hence it may increase the probability of accidents or risk of injuries.

2.2. Opening and closing of Investigations

The selection and classification of articles were based on the effects of chronic noise on physiological (cardiovascular disturbances, hypertension, hearing impairments, heart rate, hearing impairments) and psychological (nervousness/anxiety, depression, stress, cognitive impairments, motivation, fatigue, annoyance, aggression) health of individuals. Furthermore, the types of noise such as occupational and transportation noise due to limited investigated areas on motorcyclist's physiological and psychological health. Such generalized impacts on motorcyclist and its association with accidents were carefully analyzed.

The selection of articles (Table 1) further based on the criteria of being peer-reviewed journal articles in English Language, level of noise and its effects on human health, strength of association (set at $p<0.05$), measured and presented evaluation of the existing knowledge, global scale studies and age group of above 18 years.

The following keywords were searched for this study: cardiovascular diseases, hypertension, hearing impairments, cognitive impairments, neurocognitive effects, noise effects, motorcycle accidents, risk of injury, cortisol, motorcycle noise exposure, traffic noise, occupational noise alone, or in combination (Author, Year Sample).

Table 1: Psycho-Physio Analysis in relation to noise

Author, Year	Sample size	Factor analyzed	Findings
McCombe, (2003)	169	Hearing impairment, hypertension, fatigue	High noise (50-90 dBA) associated with hearing impairment, reported hypertension and fatigue. *(Motorcycle noise)*
Wang et al., (2013)	1,050	Hypertension, Heart rate	Hypertension and heart rate increases with working hours under noise > 90 dBA *(Occupational noise)*
Chang et al., (2011)	790	Hypertension, hearing impairment	Hypertension and hearing impairment with the duration of employment associated with high noise (≥96 dBA) *(Industrial noise)*
Ismaila et al., (2014)	62	Hypertension	Hypertension associated with high noise (92 dBA) *(Occupational noise)*
Chang et al., (2014)	820	Hypertension	Hypertension associated with high noise (>51 dBA) *(Transportation noise)*
Kristal et al., (1995)	3105	Heart rate	Higher heart rate associated with high noise (≥80 dBA) *(Industrial noise)*
Fredrikson et al., (2014)	115	Hearing fatigue, annoyance, stress	Temporary hearing loss, annoyance, stress are associated with prolonged noise exposure (<80 dBA) *(Obstetric Personnel)*
Girard et al., (2014)	2,943	Cardiovascular diseases (CDV), Noise Induced Hearing Loss (NIHL)	Probability of CDV increases with duration of employment under high noise exposure (90 dBA) *(Occupational noise)*
Theo et al., (2015)	2612	Performance	Impaired performance associated with high noise (≥60 dBA) *(Traffic noise)*
Jahnke et al., (2011)	47	Performance, fatigue, stress hormone	Impaired performance, higher fatigue but not significant stress hormones while working for 2 hours in high noise (L_{Aeq} 51) *(Experimental study)*
Atmaca et al., (2005)	256	Nervousness, Annoyance	Increased nervousness and annoyance associated with high noise (80 dBA) *(Industrial noise)*
Fyhri et al., (2009)	1842	Annoyance, fatigue	Increased annoyance with higher noise sensitivity associated with high noise (78 dBA) *(Traffic noise)*
Reza et al., (2015)	246	Fatigue	Physical and general fatigue increases with age associated with high noise (88 dBA). *(Traffic noise)*
Rafeffaelloet al., (2002)	62	Stress, annoyance, job satisfaction, performance	Stress Symptoms significantly increases with high noise exposure (75- 86 dBA). *(Occupational noise)*
Babisch et al., (2001)	801	Stress hormones	Higher stress hormone concentration associated with high noise exposure (40-50 dba) *(Traffic noise)*
Persson et al., (2002)	32	Cortisol concentration, annoyance, performance	Significant association between time exposure, noise condition (82-99 dBA), general noise sensitivity with cortisol concentration. *(Occupational noise)*
Cantley et al., (2015)		Risk of injuries, hearing loss	Higher risk of injuries and hearing loss at higher noise exposure (82- 99 dBA). *(Occupational noise)*
Jin Ha et al., (2015)	1790	Risk of injuries	Higher risk of injuries at higher noise exposure (≤ 80 > 90 dBA). *(Occupational noise)*

2.3. Controls of hazards and risks

The controls of hazards and risks can be explained through the probability model of noise induced psycho-physio disparities for motorcycle accidents (Fig. 1) and hypertension (McCombe, 2003). Since the noise ranging from 50 dBA to 90 dBA has the probability of increasing hypertension, motorcyclist may experience deteriorating effects while riding under complex situations that may further affect their physical and mental abilities.

2.3.1. Physiological disparities

Hearing impairment: Noise induced hearing loss is defined as the high frequency hearing loss at significant degree (Picard et al., 2008). During this study it was noticed that hearing impairment among motorcyclists are limited and no studies have been conducted among young riders (19-25 years) in the past, as well as in Malaysia.

McCombe (2003), studied noise exposure under helmet by placing a miniature microphone at rider's ear and measured sound levels under different riding conditions. The linear plot between increasing speed and noise, i.e. 90 dBA at 60 km/h and 110 dBA at 160 km/h suggested hearing impairments among the riders.

The reported results of occupational and transportation noise (ranging from 55 to 90 dBA) (McCombe, 2003) and its association to hearing impairment validate the probability of higher risk for the hearing problems among motorcycle riders. It is also stated to be associated with other psycho-physio effects, which can be the cause of road accidents and mortality among motorcyclists.

Hypertension: Noise induced hypertension tends to be increased with duration of noise exposure and noise intensity. McCombe (2003), studied the motorcycle noise exposure (>90 dBA) and its relation to hearing impairment and hypertension, but did not provide any statistical significance among noise Occupational and industrial noise shows the similar results such as Wang and his colleagues (2013), showed high significant association between occupational noise ($\geq$90 dBA) and hypertension in 21.49% workers. It was also indicated to be significantly increased with an increase in the working years ($p < 0.01$). In another similar study, Chang and his colleagues (2011) conducted the cross-sectional study on 790 aircraft-manufacturing workers in Taiwan. The multivariate logistic regression reported to have significant association of occupational noise with hypertension in relation to hearing impairment and duration of employment (Chang et al., 2011). Ismaila and his associates (2014) also carried out a cross- sectional study on occupational noise exposure (92 dBA). The analysis was carried out using one-way analysis of variance (ANOVA) on 62 samples with significant interaction of noise on hypertension. Similarly, transportation noise also tends to increase hypertension at 50 dBA and above with high significance. Chang and co- researchers (2014), conducted a study on 820 residents near main roads with high traffic noise exposure $\geq$ 51 dBA.

Heart Rate: The effects of noise on heart rate are acute as studied by Kristal and his colleagues (1995), on 3105 industrial workers. They estimated the associations between noise exposure ($\geq$80 dBA) at multiple duration during working hours. An acute effect between resting heart rate and hour of measurement (after 4 hours of exposure) was determined through multivariate analysis. The effects of noise duration on heart rate were reported to be higher among both males ($p=0.040$) and females ($p = 0.054$) and remained higher afterwards during the working hours. While, the effects of noise intensity on heart rate was not significantly associated in the case of males, but the females had higher significance ($p = 0.036$). Contradictory results were found in a cross sectional study (2010-2011) conducted by Wang and associates (2013), which showed no significant association, between occupational noise ($\geq$ 90 dBA) and cardio function. The investigation was carried out using ECG monitoring among automobile manufacturing company workers in China. Workers with 10 years of working experience under high noise exposure had significantly higher ECG than those with 0-year exposure, but lacked statistical significance (logistic regression with odd values of 1.19 and 95% CI of 0.76-1.86).

Although, the incrementing heart rate specifically due to motorcycle noise was never investigated in any study, and since motorcycle noise can be allied with occupational/ transportation noise, therefore, it might indulge the motorcyclists with increased heart rate. Since the motorcycle noise exposure is reported to be higher than 90 dBA, which can cause detrimental effects on rider's physiological health hence affecting the riding skills, which can contribute to road accidents.

Hearing fatigue: Hearing fatigue is a temporary hearing loss due to prolonged noise exposure. Fredrikson and his associates (2014), investigated hearing fatigue on 115 female obstetric personnel in relation to work noise (> 80 dBA). A significant association was reported from logistic regression model (OR = 1.04, 95% CI = 1.00 to 1.07).

The motorcyclist can have a greater chance of undergoing auditory fatigue due to high noise exposure, which can increase the risk of discomfort and contribute in psychomotor malfunctioning, which needs to be further investigated.

Cardiovascular diseases: Cardiovascular diseases (CVD) due to noise exposure cultivates with greater intensity and duration of exposure. It was evident in the case control study on retired workers ($\geq$65 years) conducted by Girard and his associates (2014), to investigate the long term risk of cardiovascular disease and noise induced hearing loss (NHIL) through occupational noise exposure above 90 dBA. It was estimated through conditional logistics regression model that long-term noise exposure i.e. $\geq$ 35 years had significant association with high probability of CVD.

CVD with motorcycle noise exposure has not been investigated, but relating to present occupational noise exposure above 90 dBA equal to motorcycle noise exposure, the motorcyclist has greater chances of emerging CVDs later in their life.

2.3.2. Noise psychological impacts

Performance: The evaluated literature showed high significance between induced noise and impaired performance. In a study by Theo and associates (2015), surveyed 2612 residents to investigate the difference in concentration among noise exposed and quieter side of the residential areas due to traffic sources (LAeq24 dBA). The results for quieter side were: OR 0.76 (95 % CI = 0.

61- 0.95) and higher noise OR 1.14 (95% CI = 1.05-1.23).

In an experimental study, Jahnke and workmates (2011), investigated the effects of high noise LAeq 51 and low noise LAeq 39 on 47 participants. They tested the cognitive, emotional and physiological status while working for two hours in an open-plan office, which was followed by four restoration conditions. The significance of high noise on reduced cognitive performance was detected to be positive, but they emphasized on further in- depth investigations.

The studies on motorcycle noise exposure in relation to their performance under complex and demanding situations has never been investigated. However, from the supportive literature of all eight studies, it is apparent that high noise will decrease performance (experimental and case control studies) at high as well as low frequency noises, which may also influence the complexity of the task and reaction time. Considering the studies performed on occupational and transportation noise, it can be assumed that the same effects can be vigilant on motorcyclist impaired riding skills due to high noise exposure, which needs to be investigated.

Nervousness: High noise can also create the feelings of nervousness in an exposed individual, which was studied by Atmaca (2005). In the study, the industrial noise exposure of different industries (80 dBA) and the relation between noise exposure and higher nervousness and annoyance among workers was reported tobe 60.96%. Similar effects can be found among motorcyclist who can develop the feelings of anxiousness and uneasiness while riding.

Annoyance: While in a similar survey study by Frediksson and associates (2014), high significant percentages between noise and annoyance at work among 115 obstetric female personnel were reported. The reported results were 49% in agreement (39.8 to 58.2) at noise exposure above >80 dBA

Fyhri and associates (2009), investigated the relationship through structural equation modeling where data results indicated a small but significant association with noise induced annoyance, furthermore, a strong relationship was indicated between noise sensitivity and other health complaints. However, if the sensitivity is removed, a statistically weak relation was determined. It was suggested that noise sensitivity acts as a modeling influential variable for increasing or decreasing annoyance, which should be considered while measuring annoyance.

While noise induced annoyance also leads to adverse health effects over time, the effects among motorcyclists has not been investigated, which upon estimation can provide a deeper understanding of the factors that can create psycho-physio misbalances among motorcyclists and its contribution as a factor for accidents.

Fatigue: In another study, Jahncke and associate (2011), investigated the difference in the effects of low and high noise on self- reported fatigue in an experimental study on open offices and restoration conditions. A statistical significance was reported after two hours of working in high noise (>52 dBA) with elevated fatigue $F(2,32) = 6.25$.

Reza and associates (2015), investigated the relation of traffic noise pollution on age and fatigue. The traffic officers (n=246) general and physical fatigue was investigated through a MFI-20 questionnaire. A multiple linear regression analysis showed a significant association between ambient noises ranging from 71.63 to 88.51 dBA with increasing physical fatigue {SE =0.96 (0.4)} and general fatigue {SE=0.98 (0.4)}. The physical fatigue showed an independent effect with high significance in relation to age (SE=Regression coefficients).

Fyhri and Klaeboe (2009) conducted a cross-sectional study in which data were estimated by structural equation modeling on traffic noise with annoyance, noise sensitivity and self-reported health outcomes. The participant's (n = 1842) health outcome such as fatigue had a weak relation, but it was much stronger with noise sensitivity. The necessity of including noise sensitivity as an important variable in noise health researchers was also suggested.

Motorcycle noise induced fatigue was investigated by McCombe and associates (2003). In their study, linear plot between high noise and increasing speed showed high hearing impairments and non-specific health complaints such as fatigue and headaches among the riders. McCombe also correlated such symptoms as similar due to occupational noise exposure.

2.3.3. Stress

The psychological state of being tense and being worried was studied as self-rated stress with high significant association to noise exposure.

In a study, Fredrikson and colleagues (2014) surveyed 115 obstetrics personnel's through a questionnaire. 42% (95% CI = 32. 9-51.1) reported noise induced work stress (<80 dBA).

The field controlled study also yield similar results, Raffaello and Maass (2002), examined 62 workers for occupational noise induced stress symptoms like annoyance, job satisfaction and performance along with other health outcomes. Significant results were computed when 10 dBA noise was reduced (75–86 dBA) experimentally between two industries. Before noise reduction, noise induced stress symptoms were 0.15 ($p < 0.001$) and after reduction it turned out to be 0.61 ($p < 0.001$).

The stress indicators include, but not limited to, increased blood pressure, heart rate, annoyance, fatigue and nervousness, which was reported to be higher among all the study types such as survey, field and experimental. It can be assumed higher among motorcyclist as well, which needs to be investigated in order to determine if the high stress level can lead to the risk of accident.

Cortisol: Physiological reaction of noise activates cortisol, a stress hormone, which is considered a biomarker for psychological malfunctioning. Babisch and associates (2001), investigated on 801 female participants on their increased stress hormones due to road traffic noise (40 to 50 dBA). The participants were selected from residential areas, whose livingroom or bedroom faces the streets. The adrenaline and non-adrenaline concentrations (urine) were determined as having a significant association of 3.00 ($p < 0.05$).

Similarly, in another study, low frequency noise (40 dBA; ventilation noise) effects were investigated in relation to cortisol concentration, rated stress, annoyance and work performance in a controlled experiment on 32 subjects by Persson and associates (2002). The cortisol concentration was tested before, during and after the test performance. The results showed 3-way significant interaction between time exposure, noise condition and general noise sensitivity ($F = 1, 28 = 4.68$, $p < 0.05$).

The supportive literature states deteriorating effects of cortisol due to noise (ranging 40 to 85 dBA) on cognitive functioning in terms of performance and annoyance. The probability of increased cortisol is more among noise sensitive individuals. Mental work (complex and prolong) also acts as a stressor on individuals due to over secretion of cortisol, which is evident from studies (Bohnen et al., 1990). Therefore, there is an intense need to investigate the effects of cortisol on motorcyclists due to motorcycle noise exposure and duration, which can be a contributing factor towards road traffic accidents due to cognitive impairments.

2.3.4. Risk of injury

The study by Cantley and associates (2015), examined the relative risk (RR) of injuries by noise and hearing loss as observed at different noise exposures: 82-84.99 dBA: RR=1.26, 95% CI = 0. 96-64. 85-87; 99 dBA: RR = 1.39,95% CI = 1.05-1.85; 88 dBA: RR=2.29, 95% CI=1.52-3.4, indicating high risk of injuries with high noise exposures.

Joon and associates (2015) explored the effects of noise exposure on occupational injuries. They evaluated 1790 factories in Korea at noise level <80, 80-89, or >90 dBA. The resulted data for odd ratio for occupational injuries significance from logistic regression model for 80–90 dBA and > 90 dBA were OR=1.92 (1.45-2.54) and 3.63 (2.41-5.47) respectively.

Noise exposures above 82 d BA increase the chances of hearing problems, which may have a lead to the risk of injury from accidents. While, motorcyclists probability of hearing impairment has been reported positive, but its association with risk of injury has never been investigated.

2.4. Maintenance of applied controls or recommendations

The model of association between various physiological and psychological impacts on motorcycle riders due to noise (Fig. 1) represents the association where double-sided arrows represent the counter associations among different traits. Physiological or psychological effects (with direct associations to noise) and may directly or indirectly lead to the risk of injuries/ accidents. Chronic noise may be an indirect factor for accidents. Hypertension has a significant and direct association with heart rate, hearing impairment, performance, stress and annoyance, which are indirectly associated via hearing impairment to the risk of injury/accidents. Heart rate directly influenced hypertension, which was established to have an indirect association with accidents. Similarly, hearing fatigue and cardiovascular diseases are indirectly associated with the risk of accidents via hearing impairment.

Cortisol on the other hand has direct influence on performance, stress and annoyance, which are all associated with hypertension (an indirect cause of accidents). Furthermore, cortisol is significantly associated with fatigue, which is also significantly associated with annoyance and performance. Similarly, nervousness can indirectly be associated with the risk of injury/ accidents via annoyance; moreover, annoyance and fatigue are also significantly associated.

It conclusion, based on the presented model that noise may trigger an undesirable physiological or psychological effects, which may lead to accidents. However, there are various factors like age, gender, duration of exposure, type of noise, individual differences that after further analysis could reveal more in depth knowledge.

2.5. Review of root cause analysis

In establishing the root cause, the model of association provides the direct and indirect associations among malfunctioning in physiological and psychological factors at high noise as well as at low frequency noise. The resulting malfunctioning's was the same for occupational and transportation noise. The studies covered field, cross sectional, longitudinal, case-control and experimental designs with almost similar results. Multivariate analysis was the common method of analysis for all the studies, but structural equation analysis provided more accurate and clearer associations between noise and physio-social effects, was also adapted. The in-depth analysis clearly establishes an association of the risk of accident towards the physiological and psychological traits in presence of chronic noise. Even though no investigation has been carried out for motorcyclists physical and mental health except for hearing impairment, (which has indirecteffects on other psychological and physiological functions), it can still be assumed that high chronic noise has the probability of inducting human errors, which might cause accidents among motorcyclists. There is need for further studies in order to analyze the noise exposure effects on motorcyclists' psychological and physiological health through structural equation modeling (Chinna and Yuen, 2015) in order to rule out the confounding factors.

Environment
Noise (> 90 dBA)
Human
(Motorcycle rider)
Activates
***Stress Reaction** (Increased stress hormones)*
Effects
***Psychological Reactions** Decrease Cognition Increase Nervousness Increase Annoyance Increase Fatigue*
***Physiological Reactions** Hearing impairments Hearing fatigue Hypertension*
Increased Heart Rate
Increased risk of cardiovascular diseases
Behavior
(Increased Probability of Accidents)

Fig. 1: The probability model of noise induced psycho-physio disparities for motorcycle accidents

3. Conclusion

The RCA exercise for this accident causation was analysed and a model of causation (Fig. 1) was developed and enabled the authors to infer that motorcycle noise sources can be associated with physiological and psychological changes while riding motorcycles. This may cause possible accidents and leading to either injury or mortality. Further research is warranted in this area.

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