PRELIMINARY RESEARCH OF HEALTH ISSUES IN WHOLE BODY VIBRATION INDUCED BY CYCLING

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1 INTRODUCTION

Cycling in western societies is being increasingly promoted as a healthy lifestyle with positive impact on all aspects of the environment and, in recession times, is viewed as a cost effective way to travel short to medium distances. As such the industry keeps developing new bikes to suit all tastes and needs, and local authorities develop dedicated cycling infrastructure.

As more and more commuters decide to adopt cycling as their favoured mode of transport, it is important to understand the scope of problems, as much as the benefits, entailed by the prolonged physical effort. The catalyst of the present research is the personal experience of the author where the purchase of a new bike led to a severe permanent headache which was presumed to come from the impact of the back wheel on road defects. This paper reports a preliminary experiment which uses a qualitative survey of cycle users, and measurement of acceleration amplitude in situ on variety of bikes and road surfaces to make a proposal for further research.

2 OVERVIEW OF HEALTH ISSUES RELATED TO CYCLING

Two different approaches were adopted to gather information on health in cycling. One was to consider publicly available research, specifically so that an idea could be developed about what the general public might think about health and cycling might do. The second was to consider information from a search in professional publications. Both approaches used search engines and library resources.

2.1 Information to the Public

To understand what information is available to a person wishing to know the health factors of cycling, the research looked at a breadth of web-sites, online forums and books, with key words focusing on 'cycling and health' or 'cycling issues'. In most cases, the information came from government bodies, charities, clubs, shops and cycling enthusiasts, and which were informative about

Table 2.1 Benefits of Regular Physical Activity
Risk of dying prematurely
Risk of dying prematurely from heart disease
Risk of developing diabetes
Risk of developing colon and breast cancer
Risk of developing high blood pressure
Reduce blood pressure in people who already have high blood pressure
Weight control
Build and maintain healthy bones, muscles and joints
Older adults become stronger and better able to move about without falling
Psychological well-being

the health benefits of cycling. They gave broad advice for choosing equipment and made recommendations for safety and comfort. When risks are mentioned they are associated with accidents related to the mixed use of roads for all types of vehicle. It is often recommended to persons with existing known medical conditions to seek advice from medical professional.

The health benefits of cycling are well known and documented and fall into the same benefits as most type of physical exercise. Table 2.1 summarises the results of research conducted by the Department of Health (2004): 'At least five a week. Evidence on the impact of physical activity and its relationship to health'[1]

2.2 Specialist information

Health issues in cycling, when not related to road accidents, are well documented in competitive cycling literature, in sports medicine and sports engineering. As with most competitive sports, cyclists push their body to such extremes that they are more likely to develop health problems compared to casual cyclists. The *Handbook of Sports Medicine and Science, Road Cycling* edited by Robert J. Gregor and Francesco Conconi[2] notes that known issues to musculoskeletal and internal problems, and remedies suggested. These issues are summarised in Table 2.2 and table 2.3. Prolonged cycling is known to be the cause of problems as well as an aggravating factor to a pre-existing conditions.

Injuries not caused by road accidents are qualified as overuse injuries, and defined as '*chronic, uncontrolled, overload, microtraumatic events. Overuse injuries occur over a period of time and, when forces applied to a structure are increased faster than the structure can adapt, or exceed its limits of adaptation. Too many miles, or too intense miles (especially hills and big gears), often cause overuse injury in cyclists. (...) Overuse injuries also occur when the bicycle is not correctly adjusted. Riders with anatomical variants may require non-standard configurations of their equipment.*'[3]

The most obvious type of discomforts and pain is related to the strain on musculoskeletal system provoking inflammation and degeneration of the tendons and bones mainly caused by jarring. In some cases the movement of the body structure causes trapped nerves, and neurological changes caused by pressure can be observed such as degrees of loss of sensation or power in the upper body. The main causes of medical consultation are hand/arm and knee issues.

The less obvious types of problem are internal and caused mainly by the increased metabolic demand on the body[3], due to the rapid decrease in body fluid and nutrients.

To avoid problems, it is recommended first to adapt the level of activity and diet to fitness level and increase the intensity of cycling as the body adapts to the strain. It is also recommended to adapt the type and all parts of a bicycle to the morphology of the cyclist to find the most sympathetic body position. In addition a degree of shock absorption can be introduced with a suspension fork, suspension seat post, a gel saddle and gel gloves.

It can be seen that some of the ailments shows in Table 2.2 and Table 2.3 are in contradiction to the benefits exposed in Table 2.1. For example, cycling is said to be beneficial for reducing the risk of diabetes and high blood pressure when physical activity is undertaken five times a week, but there is a risk that the same issues are developed through competitive cycling. As such, it is important to issue clear recommendations for the adaptation of appropriate levels of effort in relation to the individual's capacities so that cycling remains a health benefit.

Table 2.2 Musculoskeletal Issues in Cycling[4]
Neck Pains
Elbow pain
Spacular syndrome
Low back pains
White fingers syndrome
Cyclist's palsy
Carpal tunnel syndrome
Saddle sores
Haemorrhoids
Crotch dermatitis
Knees
Patellar tendinitis
Prepatellar bursitis
Arthritis of the knee
Anserine Tendinitis
Plica (patellofemoral ligament inflammation
Iliotibial band syndrome
Tight arm strings
Baker's cyst
Tibialis anterior tendinitis
Achilles tendinitis
Achilles bursitis
Heel pain syndrome (Plantar fasciitis)
Foot or toe numbness (hot or cold foot)

Table 2.3 Internal Issues in Cycling[5]

Men's Health Issues	Women's Health Issues
Penile numbness	Vulvar swelling
Penile erection (priapism)	Yeast infections
Impotence	Bladder infections
Urinating difficulties	Osteoporosis
Prostatitis	
Common to both genders	
Muscle cramps	
Headache	
Rhinorrhoea and nasal congestion	
Respiratory infections	
Fever	
Dyspnoea (not enough air)	
Exercise-induced bronchospasm (EIB)	
GI shutdown	
Heartburns and acid problems	
Diarrhoea	
Cramps	
Nausea or vomiting	
Belching and gas	
Bleeding (hidden or apparent)	
Anaemia	
High blood pressure	
Diabetes	

3 VIBRATION IN CYCLING

3.1 Survey

43 regular and non-regular cyclists answered an online questionnaire designed to understand what types of ailments and their causes regular cyclists commonly report. The issues evaluated were only of the musculoskeletal system as the self-diagnosis is likely to be more accurate than that for internal problems. An option was given to describe other health issues, and no respondents related internal problems, which supports this view concerning self-diagnosis.

The answers to the questionnaire are based on users' experience, and as such are subjective. The variations in response are likely to partly result from the level of experience of a cyclist because this level of experience is likely dictate the type of habits they adopt and the recommendations for corrective action they are likely to follow. The report of discomfort and pains is also subjective as individuals have different tolerances to them, and, as with cycling at any level of frequency or intensity, a degree of discomfort is an accepted part of the experience.

The questionnaire was distributed through a variety of cycling associations in order to help reach a range of experienced cyclists who are likely to be informed to some degree concerning health issues and cycling.

Survey Results

Even though based on a low number of participants, the results of the survey help to demonstrate the issues of interest for this paper, especially as a large majority of participants, despite their variety of experience, have indeed reported that they have been exposed to discomfort and pain through cycling.

The profile of the majority of the participants is a person, who cycles regularly to work and for leisure. The person has been doing so for a number of years and has adopted cycling as a lifestyle. They accommodate the aches and pains of cycling by choosing equipment adapted to their style of riding and they persevere in the activity despite the problems. They use a variety of roads which range from 'smooth' to 'uneven with major defects', and they understand the dynamics of the bicycle and the effect of the environment. Overall, it seems reasonable to assume that empirical knowledge is conducive to the adoption of correct equipment, particularly when such knowledge comes from a professional.

Despite the apparent knowledge of the participants, health issues are reported. This could be interpreted as a difficulty to access adequate equipment –road surfacing and bicycle- either because of cost or availability. It can be seen that the health issues detailed in Table 2.2 and 2.3 apply to regular competitive and non-competitive cyclists alike, and as such they constitute a matter relevant to public health.

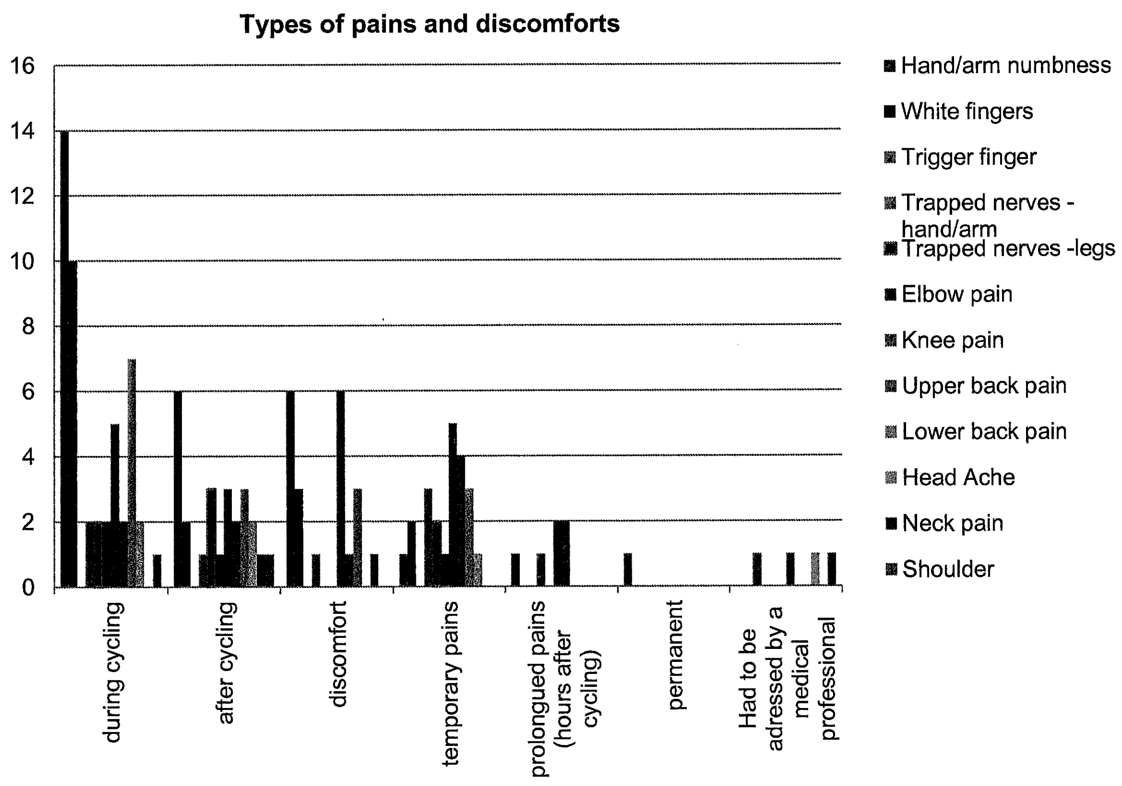

Figure 3.1: types of pains and discomfort encountered in cycling.

Figure 3.1 shows that the issues reported were felt either during or after the ride or both. The issues ranged from 'discomfort' to 'had to be addressed by a professional', and were mostly in the order of 'discomfort' to 'temporary pain'. The problems most commonly reported are from the hands – numbness and white fingers-, knees and lower back.

As seen on Figure 3.2, most of the participants reported cycling in a bent position (2), a semi-upright position (3) and an upright position (4). This is in line with the expectations that most 'road cyclists' (that is to say, cyclists who use the road to cycle at speed for leisure purposes) adopt a more bent position, while commuters adopt a variety of positions from upright to bent, with a greater occurrence of semi-bent positions. Figure 3.3 reported problems disaggregated by riding position. Most problems are reported in positions 2, 3 and 4 with a relatively equal number of issues for each position. In proportion to the number of participants who reported adopting a certain riding position, position 4 seems to create the larger number overall of discomfort issues. This is a very preliminary finding and needs to be confirmed by a lager survey.

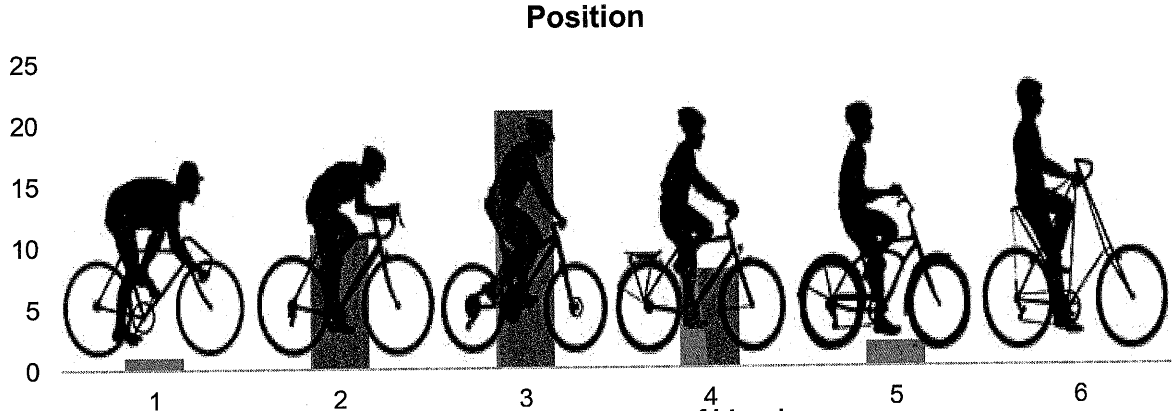

Figure 3.2: Position assumed by a cyclist over six types of bicycle.

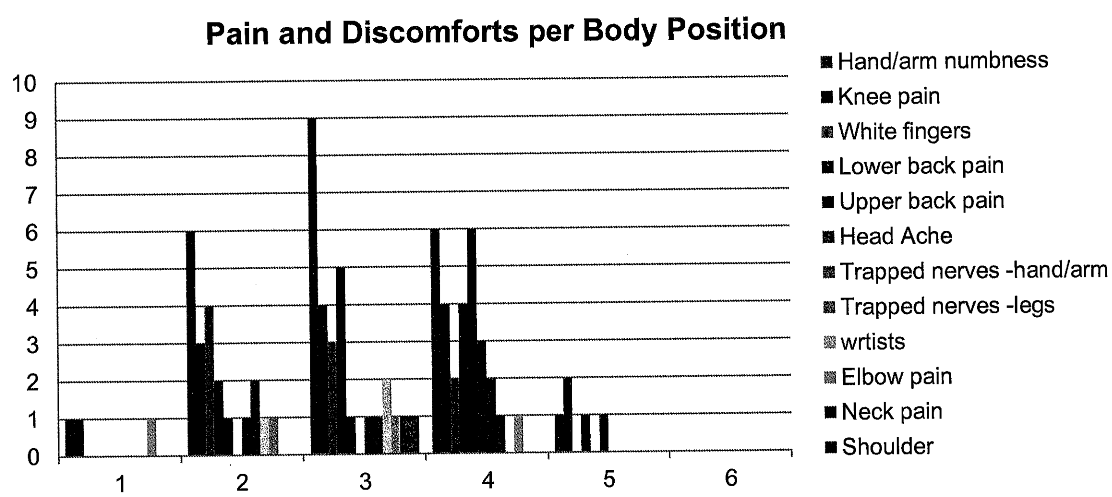

Figure 3.3: Pains and discomforts reported per body positions assumed over a bicycle.

Discomfort and pain in cycling are reported to be primarily due to riding position (27%) and, secondly, cold weather (23%). The type of road surfacing only appears in third position (14%). When shocks are reported they are perceived as coming from the front the back wheel (14%) rather than that front wheel (3%). This seems to contradict the type of problems reported, where they come mainly from the hands, but it is well known that the hand has a lower tolerance to vibration than the whole body[6], and that cold weather aggravates the condition of white fingers[7]; as such it can be considered that the self-diagnosis is accurate.

3.2 Field Experiment

A preliminary experiment was conducted to collect information on the level of vibration in relation to four grades of road surfaces, two types of frame alloys –steel and aluminium- and two types of seat posts where one is fixed and one is a suspension post. The other aspect of the experiment looked at the frequency spectrum to see where the peaks are and their implication on whole-body vibration, and particularly to the head, as headaches from cycling are the starting point of the research. The results of the experiement were used to ouline the main parameters of importance in whole-body vibration where the interface is a bicycle.

In this experiement only the weighted acceleration amplitude from the z-axis was measured, and one accelerometer was placed on the part of the frame which connects to the back wheel and at the seat post as the close to the seat as the fixing allowed. Only one accelerometer was used at a time.

3.2.1 British Standard Requirements, and Challenges of the Experiment

Research regarding vibration in cycling is limited and mostly concerns hand/arm issues.

The standard BS ISO 2631-1:1997 recommends the use of the fourth power vibration dose method (VDV, $m/s^{1,75}$) to assess the severity of peaks in vibration, instead of the second power averaging method (r.m.s, m/s^2)[8] -which tends to underestimate the peak values-, yet no VDVs could be found across the literature of whole-body vibration in transport to compare the results against. The r.m.s values are favoured and used to express daily vibration exposure (A(8), m/s^2).

The equipment used was a Svan958 cabled to an accelerometer with sensitivity designed for vibration in building, therefore oversensitive for the purpose, and the highest peaks –the values of interest- were in overload. The results of the measurements were consistent between them and were kept to outline trends.

Figure 3.4: positioning of the accelerometer.

The positioning and fastening of the accelerometer to be secure and to keep true to the reference z-axis was an issue as the connection of the frame to the back wheel did not have a platform large enough for the meter and the seat post is at an angle –between 22° and 25°.

3.2.2 Results and Discussion

The graphics in this section show results without numbers as they are used to outline general trends rather than values. Where results are compared they are the same scale of values.

The testing observed heavy constraints to repeatability as there were variations such as speed, time of exposure -0:50 to 2:30 min- and the path on the roads depended on environmental parameters –traffic flow, cars parking. As such the results were not directly comparable to each other. Nonetheless, they observed trends which could be analysed.

Figure 3.5: suspension seat post.[9]

Abreviations:
- B1-FP = Bike 1, seat post with no suspension.
- B1-SP = Bike 1, seat post with suspension.
- B2-FP = Bike 1, seat post with suspension.
- Back Wheel = accelerometer was fixed to the part of the bike frame which connects to the back wheel.
- Post = accelerometer was fixed to the seat post as close as possible to the saddle.
- Very Smooth = bitumen macadam surface with fine agregate.
- Smooth = bitumen macadam surface with medium agregate.
- Medium = bitumen macadam surface of either small or large aggregate size with minor defects such as re-instatements and small surface defects.
- Rough = bitumen macadam surface of either small or large aggregate size with major defects such as medium and large pot holes and depressions.

Time History

The time history of measurements of 100 ms integration, presented in Figure 3.6, compares the VDV over the same time period (50s) for the two extremes of road surfaces –very smooth and rough-, ridden with B1-SP and the accelerometer placed on the seat post. It should be noted that both surfaces are consistently smooth and rough over the length.

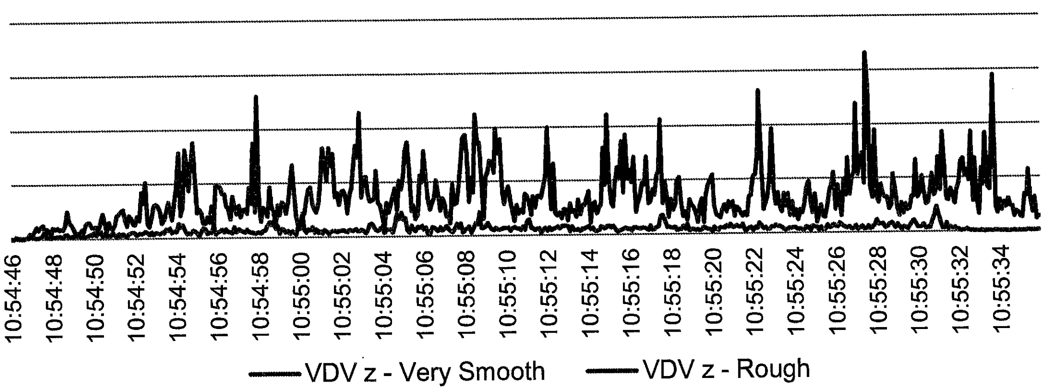

Figure 3.6: VDV time history of samples measures on a very smooth and rough road surface.

Figure 3.6 confirms that the vibration induced by rough a surface is made of a series of impacts with great variation in amplitude while the vibration induced by the smooth surface is relatively low and even. It suggests that different grades of road surface require different type of measurement averaging methods –VDV for rough surfaces and r.m.s for smooth surfaces-, which makes the comparison of values difficult.

Vibration Dose Value

The following Figures 3.7 to 3.17 show the results of the measurements of VDV on the four grades of road. The grading was an individual judgement based on personal experience of the author. A picture is placed next to the relevant road surface to give an indication of the type of surfacing implied by the terms smooth, medium and rough. No vertical axes are shown, but the upper boundary of the blue line represents the speed, and variations in the speed and the height of the grey box represents the vibration dose value.

The roads used for the testing of the smooth and medium surfaces are uphill and the gradient allowed a greater variation of speed than the roads for testing very smooth, and rough surfaces.

The length of road used for the measurements varied per grade of surface -from 'very smooth' 245 m to smooth' 610 m-; the variation impacts on the overall VDV. The time variations within the tests of the same surfaces are directly related to speed variations.

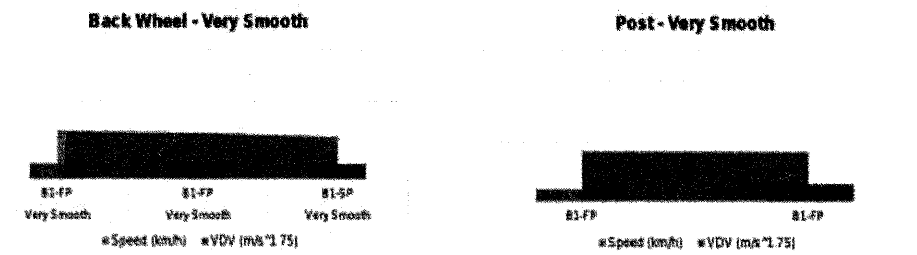

Figure 3.7 and 3.8: VDV on a very sooth road surface. Measurements at the back wheel and seat post.

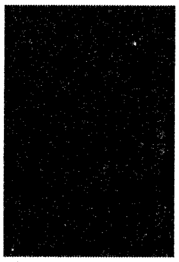

Figure 3.9: smooth road surface.

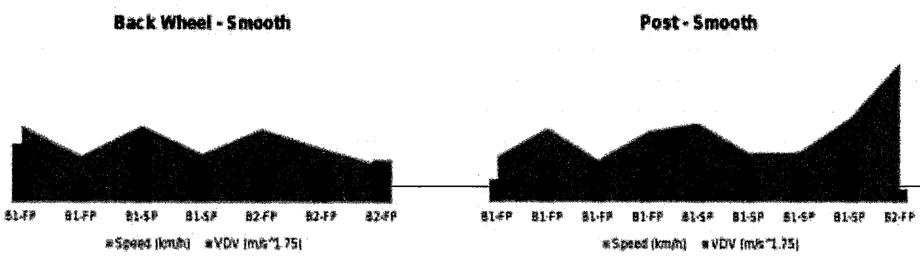

Figure 3.10 and 3.11: VDV on a very sooth road surface. Measurements at the back wheel and seat post.

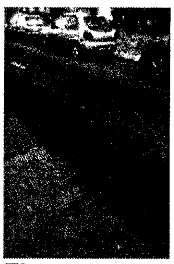

Figure 3.12: medium road surface.

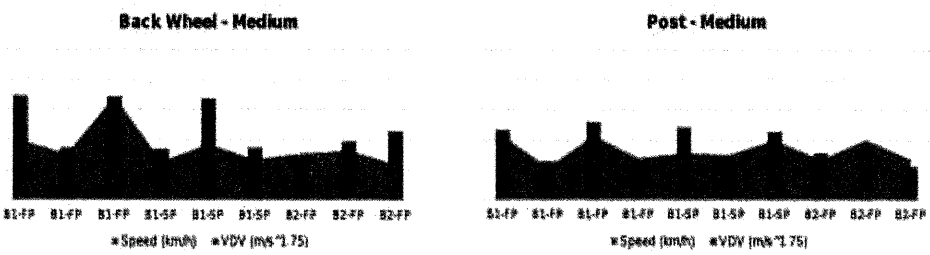

Figure 3.13 and 3.14: VDV on a medium road surface. Measurements at the back wheel and seat post.

Figure 3.15: rough road surface.

Figure 3.16 and 17: VDV on a rough road surface. Measurements at the back wheel and seat post.

So far as speed is concerned:
- VDV increases and decreases in line with respect to speed increases and decreases.
- Where the increase of VDV is of greater importance than the increase of speed, it is assumed to be caused by the lack of repeatability of the measurements, where variations of cycling with regards to the position on the road causes a variation of cycling on road defects.
- It can be observed in Figure 3.11 that the VDV is very low in comparision to the speed for B2-FP, where the speed is the highest of all the measaurments. This is either an anomaly or an indicator that the behaviour of vertical acceleration with regards to speed is not linear.

So far as road surface is concerned:
- Road surface is the greatest source of variation of VDV.
- There are more variations of VDV with the B1-FP where the surface has localised defects. This could be an indicator that the perception of vibration might be increased where the road surface is not consistanly of the same grade.

So far as vibration to the back wheel relative to Post is concerned:
Overall, the measurements at the back wheel are higher that those at the seat post. Less variations are observed where the bike is cycled uphill -lower values of speed on Figures 3.10, 3.11, 3.13 and 3.14. Cycling uphill involves more swaying movement from the bicycle, this factor could be an indicator that swaying movements have an impact on the vibration from the z-axis, and that the lateral axis in the horizontal plane needs to be part of the experiement, and potentially indeed all axes ought to be concidered.

So far as the frame is concerned:
- The VDV measured on the aluminium frame varies less between road roughness and between the location of the measurement, which could lead to the conclusion that the aluminim frame response to vibration is more constant than that of the steel.
- The variations between the back wheel and the seat post are the greatest on the rough surface, and for the steel frame. This would tend to indicate that the shock absorption qualities of the frame is greater above a certain threshold.

So far as the seat post suspension is concerned:
The difference of the results for the bike 1 between a fixed and a suspension post seem to indicate that the effectivenenss of shock aborption increases with the level of roughness of the surface.

So far as headaches are concerned:
The measurements with B1-FP, B1-SP, and B2-FP, were carried out on different days. A headache was felt at the end of cycling days with B1-FP and B2-FP, but not with B1-SP. On B1-FP and B2-FP the cyclist assumes a position close to the position 4 of figure 3.2 whereas on B1-SP the position 3 is observed. The other differences are the suspension seat-post and a gel saddle on B1-SP. It should be noted that the weather during the experiment was cold enough to have intermittent snow, which could have increased the likelihood of the development of a head ache.

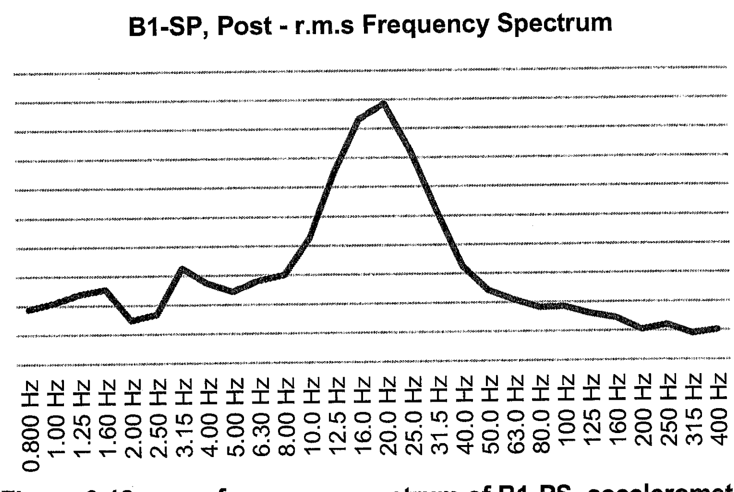

Figure 3.18: r.m.s frequency spectrum of B1-PS, accelerometer fastened at the post

3.2.3 Frequency Spectrum

The frequency spectrum was used to identify reasonant frequencies of the system of bike 1, thought to be responsible for the headache which was at the origin of the present research. The measurement was taken when the bicycle was mounted with a suspension post, with the accelerometer at the post.

It can be seen that a resonance is present at 20 Hz. According to Figure 3:19, 20-30 Hz is the natural frequency of the head which correlates with the assumption of the responsibility of the prolongued use of the bike 1 for the development and severity of the headaches.

The preleminary experiment is based on a relatively low number of measurements and the trends observed need to be confirmed or invalidated by more extensive research.

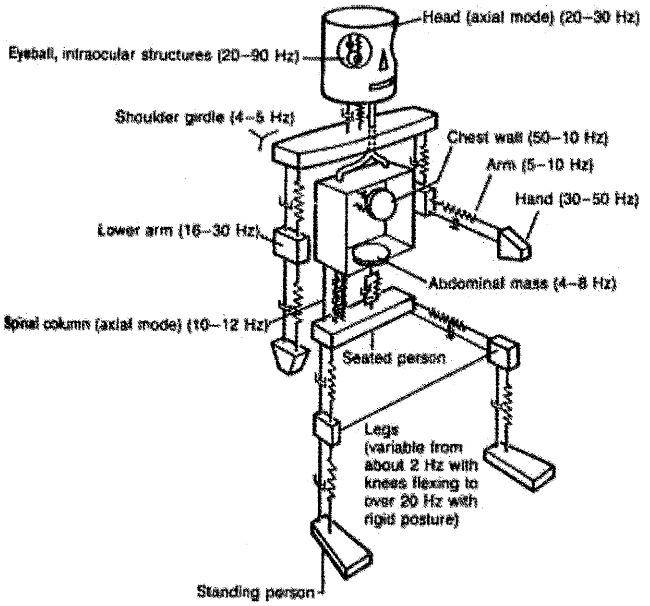

Figure 3.19: mass spring system of the body, showing its natural resonant frequencies.[8]

4 PROTOCOL FOR LARGE SCALE EXPERIMENT

The next experiment will aim to outline the amount of vibration a cyclist is subjected to when cycling on different grades of road roughness, with variations in speed, body position, type of frame and degree of shock absorption. The mass of the body will be considered as one of the parameters. A good knowledge of these parameters will allow for recommendations to be made for to the health of cycling. The research will aim to understand what proportion of the vibration affects different body parts, from the musculoskeletal system to internal parts of the body.

As seen in Figure 3.20 vibration enters a bike independently at the interface of the front and back wheel. It then enters the frame where it connects to the centre of the wheels. Vibration enters the body at the interface with the bike: on the pedals, the handle bars and the saddle. It is important to understand the contribution of each entry point as well as the independence of vibration profile of the two wheels. The research aims to take measurements on roads rather than in laboratory conditions to be as close as possible to the actual experience of cycling; additionally, the variability of speed and duration of measurements, as well as those of bike frames, tyres and the body positions, means that the experiment needs to carefully integrate

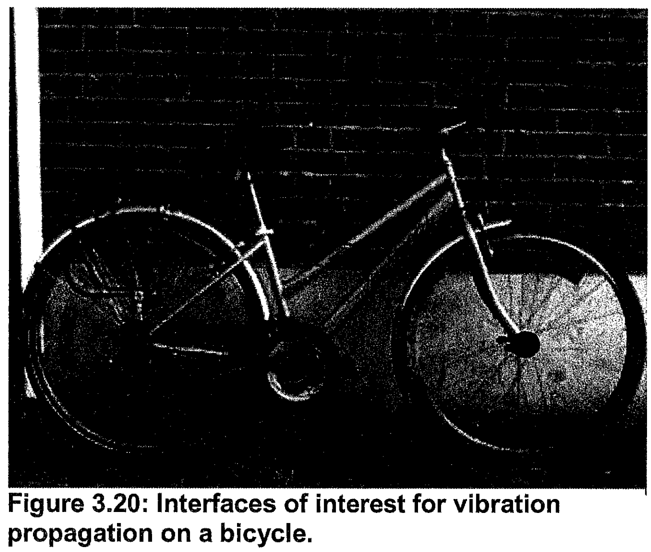

Figure 3.20: Interfaces of interest for vibration propagation on a bicycle.

the variables for comparison purposes.

There are two main types of input to the analysis: subjective data and objective data. The subjective data are explained in the Section 3.1. The objective data are more fully described below.

Objective parameters of the experiment

To remain objective the experiment needs to eliminate as much as possible unnecessary variables. As such, the following needs to be undertaken:
- Calibration of the equipment.
- Measurement of background vibration and its subtraction from the measurements.
- Use of the same lengths of different quality roads.
- Define the length of the test roads in relation to the speed, in accordance to the time-frequency bandwidth relation.
- Ensure adequate accelerometer measurement of the true x, y and z-axis accelerations at the same position.
- Have accelerometers to measure simultaneously at all the interfaces: front wheel, handlebars, back wheel, seat post, and saddle.
- Use a speedometer to record speed and ensure constant speed is maintained during measurements.

Problems to overcome to remain objective
- Manufacture a clamping device to place the accelerometer securely, perpendicular to the z axis, easy to clamp on and which adapts to all parts and angles of frames, without compromising the quality of the measurements.
- A seat pad needs to be adapted for bike measurements
- Find a satisfactory way to measure the involvement of the body position on the impact of vibration to the body.
- The measurement of vibration at the pedals remains a problem.

Relationships of interest

Relationship between acceleration amplitude and:
- Speed.
- Surface roughness.
- Frame type.
- Body position.

Observe the relationship between resonant frequencies and:
- Speed.
- Surface roughness.
- Frame type.
- Body position.
- Body parts.

The results of the experiment would need to be compared to the vibration daily exposure action and limit values given by the European Directive *2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks* arising from physical agents *(vibration)*[11]. The results may also be compared with the discomfort and pain reported by cyclists to confirm the supposed severity of the measurements.

5 CONCLUSION

The initial idea for the paper was a short research motivated by the experience of the author where commuting with a new bicycle on a new journey led to a severe and permanent headache. The research of vibration in cycling with respect to the effect on the human body revealed a lack of published data on the matter, with the available data mainly concerned with hand/arm vibration (e.g. X. Chiementin, *et al*[12]). Sports science literature revealed that cycling can have detrimental effects on a large number of aspects on health for competitive cyclists, and a survey showed that the issues on musculoskeletal systems are shared by a large proportion of a modest sample of the cycling the community. Further research is needed to identify if frequent cyclists develop internal problems too.

The gathering of field measurement data presented challenges in terms of repeatability the measurements taken were difficult to compare against each. These challenges led to the analysis comprising of observations on the data, rather than a more analytical comparison of values of acceleration amplitude with regards to speed, surface roughness, frame type, and body position. The challenges to the repeatability of the experiment are being considered further in order to identify a procedure for making accurate simultaneous measurements.

The result of this preliminary research has provided a lot of experience and the basis for a protocol for a more complex piece of research with aim of obtaining a comprehensive understanding of vibration in cycling and its impacts on whole-body vibration.

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