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Professional Driving and Adverse Reproductive Outcomes: The Evidence to Date and Research Challenges

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Abstract: The literature has reported widely on the adverse effects of whole-body vibration (wbv) exposure on professional drivers and the adverse health outcomes of lower back pain, and other musculoskeletal effects. Fewer reports exist on the adverse effects of wbv on the female reproductive system and foetal health and even less on the male reproductive system and function. This paper highlights some of the past and current literary evidence on the effects of wbv on the female and male reproductive systems and function as well as the possible reasons for the paucity of evidence in the literature. The difficulties in conducting epidemiological research in this field are explored with discussion on some of the major confounding factors which make it difficult to establish clear causal links between exposure and outcomes, especially for adverse reproductive effects.

Keywords: Professional drivers, adverse reproductive outcomes, whole-body vibration, research challenges.

INTRODUCTION

Whole-body vibration (wbv) is recognized and accepted as an important risk factor for occupational low back pain (LBP) in a variety of occupationally exposed groups [1, 2]. At least four European countries have placed wbv injury on their scheduled lists of occupational diseases [3]. It has been estimated that the typical professional driver is exposed to over 40000 hours of occupational vibration over a 30 year period [4], indicating the importance of investigating and understanding the chronic effects of this type of exposure. The European Union (EU) has acknowledged vibration as an important physical hazard, and enacted a physical gents directive applicable to vibration exposure [5] which poses a threshold level for vibration, i.e. the action level (the value above which technical, administrative, and medical provisions must be undertaken), and an exposure limit (the exposure value above which an unprotected worker is exposed to unacceptable risks) for all EU members.

Evidence suggests that LBP arising from wbv is related to early degeneration of the lumbar spinal system, and herniated lumbar discs [6]. However, many of the mechanisms of damage and effects of vibrational energy on the spinal column and surrounding tissues are still not fully understood due to the lack of a clear dose-response relationship between exposure and effect as well as the lack of evidence of disorders produced solely (or primarily) by wbv [7]. Whole-body vibration is a “generalized stressor” that impinges upon multiple body organs simultaneously [4], thereby lacking a single target organ that can be studied in detail and is one of the fundamental problems in trying to assess cause-effect relationships in this regard.

Whole-body vibration has been associated with adverse health effects on many physiological and physical structures and systems of the body. Rigid boundaries between physiological, pathological, psychological and biodynamic effects of wbv cannot easily be defined [7] due to the complex interactions and relationships within and between the human body and exposure to vibrational energy in the environment.

The effects of vibration on the human body have however been partly determined by the frequency ranges involved [8].

- Effects at less than 2 Hz, in the ranges 0.1 to 0.7 Hz most often produce motion sickness in humans, and between 1 and 2 Hz, associated effects are increases in pulmonary ventilation, heart rate, and sweat production above the level considered normal for any other stress present.
- Cardiovascular effects are maximised in the z-axis at 3 to 6 Hz, and in the x-axis at 6 to 10 Hz. The changes seen are increases in heart rate, arterial blood pressure, central venous pressure, and cardiac output; these are accompanied by a corresponding decrease in peripheral resistance. All these changes are resemble non-specific exercise responses.
- Abdominal discomfort and testicular pain are common complaints due to stretching of viscera and force applied to the spermatic cord, respectively, this can occur in the 3-10 Hz frequency range. The effects of vibration frequencies above 12 Hz are more concerned with effects on performance (vision, speech and fatigue) than physical injuries [8].

Endocrine and metabolic effects have been noted in various studies, with significant increases in blood plasma concentrations of both testosterone, and human growth hormone, and a reduction in cortisol being reported [9, 10].

WHOLE-BODY VIBRATION EXPOSURE AND FEMALES

Exposure of women to vibration has been given some examination in the literature, but as with any whole-body

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vibration research the challenges remain as to the exact health outcomes that can be related to the physical hazard. Whole-body vibration has no clear dose-response relationship, nor specific target organs or systems and this combined with the challenges of reproductive health research makes it difficult to study. It has also been shown that the response of the female body to wbv exposure differs from the male body in the resonance frequency of different anatomical regions [11], however the study by Smith did not investigate the effects on internal organs or systems at the time so this remains unclear. It has been argued by Engberg [12], that wbv affects women more than men because of their differing anatomic and physiological characteristics.

Much of the published literature on adverse reproductive outcomes in relation to vibration exposure makes reference to it as a "potential" causative agent [13-15]. Almost all authors mention of the challenges of research in this area, and that more attention and research are required in order to make stronger causal links and answer the questions as to whether or not occupational vibration exposure affects the course and outcomes of pregnancy. Abrams and Wasserman [16], raise the point that occupational vibration has received very little attention as a potential environmental hazard for working women who are pregnant. They say it is important to lobby for increased worker protection, worker education and applied research in this emerging and growing area of concern. Abrams [14], also highlighted the fact that good epidemiological data is largely unavailable relating specific pregnancy outcome factors with job categories, thus the degree of hazards of vibration, whether work related or not remains unknown. Abrams, [14] again pointed out that these concerns warrant continued study and analysis as the number of reproductive age women in the labour force continues to grow and many pregnant women remain in the workforce until late in their pregnancies.

From the research that has been conducted in the area of wbv exposure and women, most has concentrated on the effects on pregnant women [17, 18] and the unborn foetus [19, 20]. Much of the readily available information in regards to females and vibration exposure, involves the control of risks to the foetus during pregnancy as outlined in various governmental and institutional guides, codes of practice and occupational health and safety requirements [21-26].

Seidel and Heide [18], completed a critical review of the literature in which they examined 78 papers (total) concerning wbv exposure and adverse health effects. With regards to the effect of vibration on the female reproductive organs they state that at the time these conditions had been investigated less profoundly with regards to epidemiological methods than other vibration related conditions. They also highlighted an important factor that none of the papers (n = 6) concerning women and vibration exposure had explicit information on how differences in women's ages and the number of deliveries were considered or eliminated when comparing exposed groups against non-exposed, thus bringing the results into question. Their overall conclusions were that wbv exposed women were at a higher risk of menstrual disorders, proneness to abortions and complications of pregnancy, as well as anomalies of the position of the female reproductive organs when exposed to or above the wbv exposure standard at the time. They also mentioned that the findings should be interpreted with caution due to the limitations in the studies. The authors, Seidel and Heide [18] also discuss a study by Frolova [27], which indicated that wbv exposure induced a distinct increase in blood volume during the phases of ovulation and menstruation which they say may hint at a possible biological mechanism.

Some wbv laboratory studies have been published that examined the effects of vibration exposure on the foetus. Peters *et al.* [19] in a study of the acceleration of the foetal head induced by vibration of the maternal abdominal wall in sheep showed that vibration of the extra-abdominal wall resulted in frequency-dependent rises in vibration levels at the intra-abdominal wall, from 4 - 140%, but only a 4% maximum increase at the foetal head was recorded which the authors attributed possibly to the acoustic impedance offered by the protective maternal fluid media surrounding the foetus. This indicates that vibrational energy can reach the foetus even though it is somewhat attenuated. The resonance frequencies of the pregnant sheep uterus were studied by Peters *et al.* [28], using low frequency mechanical vibration sources, and the authors found a region of resonance between 6 - 18 Hz. They mention that although uncertainty remains as to the adverse reproductive effects of excessive sound and vibration, there are sufficient data to infer that vibration at resonance frequencies should be minimised or avoided during pregnancy.

Further studies by Mamelle *et al.* [17] examined prematurity rates and occupational activity during pregnancy (n = 1928). The authors found that working on "industrial machines" did increase the odds of prematurity (OR 1.7 95% CI 1.1-2.0) even when controlling for confounders by using matched controls. The authors could not discern between or attribute prematurity specifically to vibration exposure alone, and in fact other factors such as physical exertion, mental stress and environmental factors contributed equally or more to the risk. The paucity of evidence and methodological and other problems in many of the reported studies warrant caution in interpretation of the findings as definitive.

It is interesting to note that although the studies to date on vibration exposure and women have been limited compared to other areas of vibration research on lower back pain and musculoskeletal injuries, much of the warnings and foetal protection concerns have been incorporated into many current documents adopted by government bodies [22, 24], non-governmental organisations [5], city councils [26], universities [29], and the military [25] to name a few. Paradoxically not much mentioned about the specific effects of wbv in males is made.

WHOLE-BODY VIBRATION EXPOSURE AND THE MALE REPRODUCTIVE SYSTEM

The literature that does examine the possible links between wbv and reproductive effects in males are also weak in making the case for cause-effect relationships. The paucity of available literature further asserts the need for further research in this area. Much of the available published literature involving males is from the early seventies with few recent additions, most of which make reference to the difficulties of conducting well structured and controlled studies in this area.

In one early study in 1974, a statistically significant difference in the reported rates of various disease conditions was reported when comparisons were made between exposed drivers (n = 1448) and the control groups in three of 37 disease categories studied, one of which was "diseases of the male genital organs" [30]. The authors acknowledge that the multitude of interlocking causal factors and the relative lack of environmental and clinical measurement data for the operators of commercial vehicles hamper the inferences that can be drawn about adverse long-term effects and thus warrant tentative conclusions.

A follow up study amongst heavy equipment operators again found significantly elevated relative risk among the exposed group in three of the thirty disease categories studied [31]. One of these, "diseases of the male genital organs", especially prostatitis, was thought to be particularly important by the researchers with a significantly elevated relative risk for the exposed group and increased number of health claims. The authors however state that it would be prudent to consider any findings in the case of exposed vs. control comparisons with caution as further analysis indicated a statistically significant tendency for workers to drop out of the control group with a higher probability than the exposed. The authors admitted a plausible explanation for this was not forthcoming. Another study in coal and sand miners [32], found a significantly greater incidence of disorders of the digestive, circulatory systems and the urogenital organs in wbv exposed men and women but no detailed data were available for further inferences to be made.

A study comparing the fertility indices of 80 professional drivers and 159 non-exposed controls [33], showed a significantly higher percentage of the drivers having "disturbed" fertility indices (66.25%) compared to the control group (35.85% $P < 0.001$). The authors concluded that professional drivers should be warned of this possible risk to fertility rates.

Penkov *et al.* [34], reported on a study that examined the male reproductive function in workers exposed to occupational vibration, and they asserted that studies on the effects of vibration on male reproductive function were still rare at the time. The researchers used semen analysis to study the effects of vibration on spermatogenesis in workers of different occupational groups (professional drivers, miners, engine drivers and a control group). The results indicated that vibration exposed workers had considerably more deviations in their sperm parameters and fertility rates when compared to the control group. In fact when evaluating the fertility capacity it was established that less than 48% of the drivers were classified as having normal fertility, 20% had poor fertility, 27% moderate and 4% were sterile. The authors surmise that the mechanisms affecting the reproductive function under the influence of vibration could take place either by direct transmission of vibration energy to the cells and reproductive organs, indirectly by the influences on receptors and activation of the nervous system, or changes in the haemodynamics of organs and tissues. They state the established changes in the male reproductive function in professional groups justified more detailed investigations to evaluate risk factors and also to develop statistical mathematical models to predict the health risks of exposed workers.

Kirkov *et al.* [35], showed that in miners normal and raised sexual activity was indicated in the first year of employment, however after 3-5 years disturbances of orgasm (decreased or absent) appeared as well as disturbances of erection, ejaculation and libido. Similar disorders are described in other professional groups exposed to vibration [34], showing decreased motility of spermatozoa, reduced numbers, and the presence of increased pathological forms of spermatozoa, [36, 37].

Penkov and Tzvetkov [38], studied the effect of vibration on the male reproductive system and function in a later study and made mention of various studies (published mainly in Russian and Bulgarian languages). They examined the reproductive effects on various vibration exposed groups, with the findings mainly pointing to sexual disorders [39], reduced potency and reproductive capacity including impaired spermatogenesis [40], increased frequency of azoospermia, teratospermia, and asthenospermia [41], and increased size and weight of the prostate and seminal vesicles [42]. The last paper is mentioned to have recorded erectile dysfunction (ED) as a frequently reported effect amongst lorry, tractor and combine harvester drivers, along with decreased potency, premature ejaculation, and reduced reproductive outcomes [42].

Penkov and Tzvetkov [38], make mention of an unpublished study in which the sexual and reproductive function of 50 miners with "vibration disease" were compared to a control group of 30 fitters and turners. The findings are significant in that miners showed a highly significant difference in the reporting of erectile disorders when compared to the controls (40% vs. 6.6%, $p<0.01$) as well as in other measures of sexual function such as decreased libido (38% vs. 6.6%, $p<0.01$), and "disorders of ejaculation" (46% vs. 6.6%, $p<0.01$). The authors however, do not give details as to why the study was unpublished, or what other concomitant exposures could have been present that may have influenced the results. These results thus should be interpreted with caution. They also carried out further detailed analysis of semen specimens collected from the two groups and found the miners had worse sperm parameters in all respects when compared to the control group.

The authors of another study [40] found that out of 2984 patients consulting for infertility, 9.4% were professional drivers, whereas that particular occupational group only accounted for 3.8% of the general population in the catchment area they studied. They also found the incidence of the most severe sperm anomalies was correlated with the number of years driving, and with the use of agricultural and heavy industrial machinery with high levels of vibration.

In a critical survey of the literature into the long-term effects of whole-body vibration, Seidel and Heide [18], also mention that non-uniform results on the occurrence of diseases of the male urogenital system had been published at the time. They make reference to only three papers [30, 43, 44] (some of which have been discussed above), in which they merely mention that some have reported a higher incidence of prostatitis.

It can be noted that much of the research into the reproductive effects of whole-body vibration has been conducted in Eastern European countries such as Bulgaria and Russia.

The situation is complicated by the limited number of published papers in the past years, and the fact that the majority of the ones that do exist are published in languages other than English. Also limited mention is made of ED as a possible outcome of vibration exposure, however some anecdotal evidence does exist as to a possible link, and in a study conducted by the author in forklift drivers in South Africa examining the prevalence and severity of lower back pain, numerous spontaneous reports of ED were made with drivers adamant it had a link to the vibration exposure they experienced [45]. A small number of diverse information sources do mention ED (impotence) as a potential adverse health outcome of wbv exposure [46-48] but no clear research evidence exists at this time. Erectile dysfunction is however a well established male health problem and it is estimated that up to 30 million men in the USA have some degree of ED [49], and in Australia the prevalence rate has been estimated at around one million [50] many of who would be exposed to vibration at work.

RESEARCH CHALLENGES IN WBV AND REPRODUCTIVE OUTCOMES

Schilling and Andersson [51], point out that epidemiology has an important role to play in determining the incidence and severity of disease and injury in a community, and attempting to sort out the relative importance of the various interacting aetiological factors. Aetiological investigations identify possible causal factors and quantify the occupational share in the multi-factorial aetiology [51]. Research challenges have been found in the designing, sample sizes and statistical power of reproductive health studies along with the sensitivity of the topic amongst subjects, differences in levels of exposure amongst different study groups, differences in accuracy and sensitivity in detecting reproductive outcomes, problems with definitions and selection of suitable control groups and confounding variables [52]. These all seem to have limited the study of the occupational link with adverse reproductive effects and resulted in a large area of unclear cause and effect. Confounding variables are thus factors (known or unknown) that may have an indistinguishable effect on an outcome variable. Some of the most common confounding factors in reproductive health studies are discussed below.

CONFOUNDING FACTORS

Age

In a study by Grzesik [32], it was noted that the incidence of disorders of the urogenital organs of men and women were increased in wbv exposed individuals, and that the variety and frequency of health disorders were greater in workers over 45 years of age. The question raised by this is, if this increase in incidence was because of age or due to a longer exposure period? The author [32], does not mention of this important confounding factor. In reproductive and erectile dysfunction studies one of the most important risk factors (and confounders) has been shown to be age, and in an Australian study [53], age was found to be the strongest contributing demographic factor for ED. This problem is further compounded by the ageing workforce in many developed industrialised nations which make it difficult to unravel the relationships between and within variables.

Occupational Heat Exposure

Heat exposure has been linked as a risk factor to reduced fertility, and it has been found by Thonneau *et al.* [54] that the time to pregnancy for two subgroups, those exposed to heat, and those who spent more than three hours per day seated in a vehicle, took significantly longer to obtain a pregnancy than for the controls. The authors concluded that occupational exposure to heat is a “weak” risk factor for male sub-fertility. In a later review of the literature [55], it was concluded that male heat exposure seems to have a deleterious effect on male fertility and can be considered a significant risk factor for male infertility. The authors conclude that in men subjected to repeated abnormal situations such as driving or being exposed to high temperatures at work, there may be chronic thermo-dysregulation which may result in substantial changes in sperm characteristics. This factor has a confounding effect on any study attempting to study vibration exposure and its effects on fertility, as both exposures to heat and vibration occur at the same time, and are again difficult to disentangle in order to identify and attribute causal links.

Prolonged Sitting

Prolonged sitting has been shown to lead to circulatory disorders in the pelvic area, which according to Penkov and Tzvetkov [38] may contribute to the development of varicocele, with possible deterioration of semen quality. Again sitting and vibration exposures occur concurrently in drivers.

Compound Exposures

Sheiner *et al.* [56] point out that compound exposures are often linked to the same or similar outcomes, and the authors mention professional drivers as an example, where exposures to products of fuels, noise, vibration, emotional stress, physical load on the pelvic region, and increased temperature of the pelvis because of prolonged sitting may all contribute to adverse reproductive outcomes.

Illness

Chronic systemic illnesses such as diabetes, heart disease and hypertension are mentioned [57] as being commonly associated with ED specifically. These factors would thus need to be controlled for in any epidemiological study and excluded as far as possible. Sullivan *et al.* [58], also discusses smoking, atherosclerosis, and hyperlipidaemia as important risk factors for ED. All of which may occur in any population of interest in a wbv/reproductive effect study.

Epidemiological Research

Some of the challenges of reproductive epidemiological research can also be found and paralleled in musculoskeletal epidemiological research in that back disorders have very similar characteristics to adverse reproductive outcomes. They are multifactorial in nature and much of the research conducted in the past has presented crude associations between risk factors and back disorders with risk factors determined at qualitative levels and health end points defined as non-specific disorders [59].

Thus the challenge of the assessment of risk factors lies in finding the means to reliably assess the relative magnitude

Table 1. Causal Inference Relationships of Adverse Reproductive Outcomes from Whole-Body Vibration Exposures. (Adapted from Hill [60])

Criteria	Association	Comments
Strength of association	Weak	Published evidence lacking due to small number of available studies.
Consistency of findings	Weak	Small number of studies, however existing studies have shown similarities.
Biological plausibility	Medium	Some animal and other experiments indicate possible mechanisms.
Temporal sequence of risk and effect	Unclear	Exposure precedes effect, but reproductive effects are also associated with other causes.
Dose-response gradient	Unclear	Relationship remains unclear due to difficulties in assessing dose and associated response.
Specificity of risk factor for outcome	Weak	Reproductive effects and disorders difficult to associate with specific cause/exposure.
Coherence of the evidence	Weak	Coherence with biological background and previous knowledge unclear due to limited number of studies.

of the interrelated risk factors in order to identify the causal and aggravating factors [59], with health end points more clearly defined.

In principle, causality of association requires evidence on the strength of association, consistency in findings, biological plausibility, temporal sequence of risk and effect, dose-response gradient, specificity of risk factor for the health outcome, and coherence of evidence [60]. Many of these factors cannot easily be satisfied with regards to whole-body vibration exposure and reproductive outcomes. The criterion on temporality calls for cohort studies which are not commonly encountered in the study of the epidemiology of musculoskeletal disorders [59], nor reproductive disorders. Although proof of reversibility makes a very strong case for a particular risk factor, intervention studies on work-related risk factors for LBP or other wbv disorders that show a decrease in occurrence after workplace improvement or changes in vibration exposure are very scarce or non-existent [59] as in the case of reproductive effects linked to wbv exposure.

CONCLUSION

From the evidence to date it can be reasonably inferred that exposure to prolonged whole-body vibration while operating a vehicle shows unclear and weak evidence of adverse reproductive outcomes in males or females. The limited research and anecdotal evidence that does however exist should not be ignored and can be considered as the strongest indicator so far that adverse reproductive effect could be present and should be investigated further.

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