NOISE EXPOSURE DURING PREGNANCY, BIRTH OUTCOMES AND FETAL DEVELOPMENT: META-ANALYSES USING QUALITY EFFECTS MODEL

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ABSTRACT

BACKGROUND: Many women are exposed daily to high levels of occupational and residential noise, so the effect of noise exposure on pregnancy should be considered because noise affects both the fetus and the mother herself. However, there is a controversy in the literature regarding the adverse effects of occupational and residential noise exposure on pregnancy should be considered because noise affects both the fetus and the mother herself. AIM: The aim of this study was to conduct systematic review of previously analyzed studies, to add additional information omitted in previous reviews and to perform meta-analyses on the effects of noise exposure on pregnancy, birth outcomes and fetal development. MATERIAL AND METHODS: Previous reviews and meta-analyses on the topic were consulted. Additionally, a systematic search in MEDLINE, EMBASE and Internet was carried out. Twenty nine studies were included in the meta-analyses. Quality effects meta-analytical model was applied. RESULTS: Women exposed to high noise levels (in most of the studies ≥ 80 dB) during pregnancy are at a significantly higher risk for having small-for-gestational-age newborn (RR = 1.19, 95% CI: 1.03, 1.38), gestational hypertension (RR = 1.27, 95% CI: 1.03, 1.58) and infant with congenital malformations (RR = 1.47, 95% CI: 1.21, 1.79). The effect was not significant for preeclampsia, perinatal death, spontaneous abortion and preterm birth. CONCLUSION: The results are consistent with previous findings regarding a higher risk for small-for-gestational-age. They also highlight the significance of residential and occupational noise exposure for developing gestational hypertension and especially congenital malformations.

Key words: noise exposure, pregnancy, birth outcomes, fetal development, meta-analysis, quality effects model

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РЕЗУЛЬТАТЫ:

Женщины, экспонированные на высокие шумовые уровни (в большинстве исследований ≥ 80 dB), во время беременности подвергнуты значительно более высокому риску родов ребенка небольшой массы тела для гестационного возраста (RR = 1.19, 95% CI: 1.03, 1.38), риску гестационной гипертонии (RR = 1.27, 95% CI: 1.03, 1.58) и риску родов ребенка с врожденными мальформациями (RR = 1.47, 95% CI: 1.21, 1.79). Эффект не оказался значимым для прематурии, перинатальной смерти, спонтанного аборт и преждевременных родов. Заключение: Результаты подтверждают уже установленный повышенный риск родов маленького для гестационного возраста ребенка; подчеркивают также значимость коммунальной и трудовой шумовой экспозиции для развития гестационной гипертонии и особенно для развития врожденных мальформаций.

Ключевые слова: шумовая экспозиция, исход беременности, развитие эмбриона, мета-анализ, качество эффектов модель
INTRODUCTION

Noise pollution is continuing to grow as a result of urbanization and industrialization.1 Eighty million people in Europe alone are exposed to community noise levels above 65 dB,2 and it has been estimated that up to 2% of the gross domestic product as well as one million healthy life years are lost every year in Europe due to noise pollution.14 Occupational noise is also associated with adverse health outcomes: hearing loss, performance impairment, cardiovascular diseases and mental exhaustion.5 In 2000, as much as 20% of all European workers were exposed to noise so loud that it required raising their voice to talk to other people.6 There are various risk groups particularly sensitive to environmental noise and one of those is pregnant women.

As a unique environmental stressor noise exerts both direct and indirect effects on humans. Noise higher than 85 dB might lead to permanent hearing impairment.7 Because of its indirect effects noise is considered a risk factor for hypertension, ischemic heart disease, annoyance and sleep disturbance.8-12 Approximately 210 000 of all coronary incidents in Europe every year can be attributed to traffic noise exposure.13

As many women live and work in highly noisy environments, noise exposure is in the focus of attention of public health experts when pregnancy is involved. Generally, some authors find that women might have elevated risk of noise induced cardiovascular alterations.14,15 Others even proposed that the higher noise sensitivity of women should be considered an independent risk factor for cardiovascular diseases.16 If changes in cardiovascular and endocrine function occur under noise conditions, they can have some adverse effects on human pregnancy. The human body reacts to environmental noise with a general stress response mechanism leading to neuroendocrine and cardiovascular alterations.17 It activates the amygdala, some cortical limbic and hypothalamic centres18, thus affecting synaptic links in the reticular formation and mesencephalon, as well as emotional and cognitive pathways of perception through cortical and subcortical structures19,20. Ultimately this leads to stimulation of the sympathetic-adrenal axis.21 Stress-release of maternal catecholamine may increase blood pressure and uterine reactivity and thus decrease placental function leading to hypoxia of the fetus.22 Maternal cortisol might pass through the placental barrier and interfere in the regulation of the fetal hypothalamic-pituitary-adrenal axis, or stimulate the placenta to secrete corticotropin releasing hormone.23 On other hand, as the intrauterine environment is rich with externally generated noise passing through the abdominal wall,24 noise energy might affect the fetus directly.25,26 Sound is easily transmitted to the fetus through the abdominal wall which has an attenuation of about 10 dB or less in the low frequency range.

However, there is a controversy in the literature regarding the adverse effects of both occupational and residential noise on pregnant women and their fetuses. Some authors find association with birth defects, shortened gestation and decreased birth weight, while others find no effect.27 Recently a systematic review by Hohmann et al.28 found no evidence for effect of noise exposure on pregnancy, birth outcomes or fetal development. It, however, did not review all evidence that was present at that moment. Previously the government of Quebec had reported a thorough and extensive meta-analysis on the effects of workplace noise on pregnancy and found evidence suggesting that in the presence of occupational noise exposure ≥ 85 dB pregnancy leads to low birth weight for the gestational age, and might possibly cause spontaneous abortion, preterm birth, preeclampsia and gestational hypertension.29 Both these papers have their limitations: Hohmann et al.28 applied only qualitative appraisal of the data and did not include all available evidence, while Croteau, et al.29 reviewed only studies dealing with occupational noise. Although they adopted sophisticated quality assessment methodology and used meta-regressions, they adhered to the DerSimonian-Laird random effects meta-analytical model, which has been criticized for its limitations.30,31 Finally, since the systematic literature searches of these two studies were performed, new evidence on the topic might have been accumulated.

AIM

In this paper we focus only on the effect of intrauterine noise exposure on pregnancy, birth outcomes and fetal development. The aim of this study was to perform a systematic review of previously analyzed studies, to add additional information not included in previous research and to perform meta-analyses on the effects of noise exposure on pregnancy, birth outcomes and fetal development.

MATERIAL AND METHODS

SEARCH STRATEGY

This research was greatly facilitated by previously published high quality papers on the topic.28,29 Most
of the literature sources on the relationship noise—pregnancy outcomes was readily collected, summarized, reviewed and available from government of Quebec’s report.  Additionally, we carried out systematic search in MEDLINE, EMBASE and generally the Internet using the search engines PubMed, ScienceDirect and Google (studies published before December 23, 2013). Two of the authors performed the searches independently. English, Russian and Spanish language articles were screened on three levels: titles, abstracts and full-texts. Inclusion criteria were: studies dealing with noise exposure as a primary or secondary factor and its effect on pregnancy, intrauterine development or birth outcomes; observational and experimental studies involving humans or reviews/meta-analyses. Papers describing research on hearing impairment due to fetal noise exposure or research in intensive care units were excluded as they were not in our scope. The following free-term keyword combinations were used: “noise + pregnancy”, “ruido + embarazo” and “шум + беременность”. PubMed retrieved 653 results with no filters applied while in ScienceDirect English language search was limited to topics associated with prenatal development, pregnancy outcomes and intrauterine imaging diagnostics – 621 results were retrieved in English, 278 in Spanish and none in Russian. Additionally, Google search provided two more papers in Spanish. Hand searching through the reference list of a report of the American Academy of Pediatrics provided five articles not included in previous reviews. Hand search of the reference lists of articles available at the web-page of Scandinavian Journal of Work, Environment & Health retrieved five more studies previously not meta-analyzed. The abstract of Knipschild et al.’s paper was retrieved and additional data about it had been abstracted by Hohmann et al.

Studies which, after careful consideration, were deemed irrelevant to the topic were dropped from further processing (for example, Heidam). Due to limited access to repository information, some of the articles could not be retrieved in full-text and if the abstract or previous reviews did not provide sufficient data to assess their quality or calculate effect size estimates, they were not included in the meta-analyses. Inter-rater agreement for the included studies was acceptable (Kappa = 0.74) and any discrepancies were resolved after discussion with a third expert.

**Quality Assessment**

Individual study quality assessment methodology was adopted from Croteau et al.  Briefly, their checklist assigned a total of 18 points for perfectly credible study for external and internal validity according to the following elements: country where the study was conducted, period when the study was conducted, mode of selection of the population, participation rate, definition of the effect on pregnancy, measurement of the effect on pregnancy, definition of noise exposure, selecting the comparison group, measurements and covariates. For more detailed information the reader is referred to Croteau, et al. Individual study scores were recalculated as relative shares from the maximum 18 points and re-scaled between 0 for a low quality study and 1 for a perfectly scored.

**Data Extraction and Processing**

Meta-analyses were performed to estimate the effects of noise exposure (both occupational and residential) during pregnancy on the risk for gestational hypertension (blood pressure > 140/90 mm Hg), fetal malformations, small-for-gestational-age infants (≤ 2500 g/smaller than the 10th percentile), preeclampsia, preterm birth (≤ 37 gestational week) and perinatal death. Two of the studies had low birth weight as outcome, while the rest assessed small-for-gestational-age infants according to the classification of Croteau et al. Although these are different entities, Croteau et al. used the results of Peoples-Sheps et al. as representative of small-for-gestational-age, while in fact they measured low birth weight (≤ 2500 g). They used low birth weight as a proxy for small-for-gestational-age claiming that it could be the result of preterm birth, small for gestational age, or both. Magann et al. on the other hand, assessed intrauterine growth restriction, but this outcome was also interpreted as small for gestational age by Croteau, et al. Hence, we felt comfortable including the two studies mentioned above along with the others representing small-for-gestational-age infants.

MetaXL v.1.4 add-in for Excel (http://www.epigear.com) was used to conduct the analyses. Additional data imputation was performed with Excel spreadsheets or by hand. Relative risks (RR) were chosen as effect size estimates.

Twenty nine studies were included in the meta-analyses. Initial data of about 24 of the studies were extracted from Croteau et al. For the studies that we retrieved in full text the effect size estimates reported by Croteau et al. were confirmed. However, careful read of their report reveals that they actually mixed odds ratio (OR), RR and in
some occasions expected to observed ratio. Interpreting OR as RR leads to overestimation of the effect. Moreover, when a straightforward estimation of RR is an option given the original study data, there is no reason to use OR as a substitute to RR. On the other hand, using OR in this case might be justified because it is adjusted for relevant confounders like demographics, previous pregnancies, socio-economic class, other exposures, etc. Therefore, whenever possible we calculated the adjusted RR from the original data in the studies according to Zhang & Yu, and when it was not, we adhered to the adjusted OR. For the five studies that we identified and have not been previously meta-analyzed we calculated RR. Studies with zero events in control group were included in the meta-analyses in order to provide a more conservative estimate of the effect size. In this case the standard continuity correction of 0.5 was used according to Cox, (cited by Friedrich et al.). When RR or OR were reported for several noise exposure categories, those using the highest exposure as a cut point were included in the meta-analyses.

All effect size estimates for the different outcomes were entered into MetaXL which was set to produce pooled RR. Of all data reported in the studies we extracted the effect sizes adjusted for most of the relevant confounders. The approach of Zhang & Yu is criticized and it produces too narrow 95% confidence intervals, but given that most outcome measures in these meta-analyses are relatively rare in the population and that in environmental epidemiology we are often interested in the pooled point estimate rather than the 95% confidence intervals around it, we did not expect that our findings would be associated with significant imprecision.

Quality effects meta-analytical model was applied. According to Overton, if the studies included in the meta-analysis differ in systematic way from the possible range in the population, they are not representative of it and the random effects model does not apply. Therefore, the quality effects model proposed by Doi and Thalib was applied. It uses a quality index Q representing the probability the judgment of that study is credible. From Q a study specific composite is generated that takes into consideration study specific information and its relationship to other studies to re-distribute inverse variance weights.

Heterogeneity was explored using the chi-square test. The quantity of heterogeneity across studies was measured by the I² statistic. According to the I² values, heterogeneity was considered low (< 25%), moderate (25 – 50%) and high (> 50%). Sensitivity analysis was performed by assessing the contribution of individual studies to the summary effect estimate by excluding each trial, one at a time, and computing meta-analysis estimates for the remaining studies. Publication bias was not assessed due to inter-study heterogeneity and the limited number of studies included for each individual outcome. Results were considered statistically significant at p < 0.05. All analyses were carried out with MS Excel v. 2010.

RESULTS

In this paper we will first present a brief overview of those studies previously not subject to systematic review. Table 1 reports their characteristics according to the quality assessment procedure of Croteau, et al. For additional information regarding the rest of the studies included in the meta-analyses the reader is kindly asked to consult Croteau, et al. and Hohmann et al.

Of all included studies nine were case-control, two were cross-sectional, four were cohort, 13 were retrospective and one was ecological. (Ecological study was defined as one using aggregated data.) The sample sizes varied considerably from 179 to 225. Small-for-gestational-age was an outcome in 12 studies, preterm birth in 11, gestational hypertension in seven, spontaneous abortion in five, preeclampsia in three (Irwin et al. was included twice with results for nulliparous and multiparous women), three assessed perinatal death and five - congenital malformations. Ten studies assessed more than one outcome. Adjustments for relevant confounders varied but they were to some extent accounted for by the quality scores. Finally, two studies were dealing with residential rather than occupational noise exposure.

There is a 19% risk for small-for-gestational-age if the mother has been exposed to ≥ 80 dB during pregnancy (Fig. 1). All studies used a cut point of approximately 80 dB risk noise exposure assessed either by specific question about the acoustic environment at work or by quantification by industrial hygienists. Sensitivity analysis revealed that by excluding each study one at a time the pooled RR remained significant in the range 1.16 – 1.27, with the only exception of excluding McDonald et al. (RR = 1.15, 95% CI: 0.97, 1.36). However, most of the studies used OR and this was one of the
Table 1. Characteristics of the studies not previously reviewed or meta-analyzed (description is given according to Croteau et al.29)

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>External validity (2)</th>
<th>Population</th>
<th>Effects on pregnancy</th>
<th>Noise exposure</th>
<th>Controlling for confounders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numinen, 1989²²</td>
<td>Retrospective study, n = 1 475</td>
<td>Finland, 1976 – 1982, workers (2)</td>
<td>Mothers of infants with malformations (2)</td>
<td>≥ 85% (2)</td>
<td>Gestational hypertension (≥ 20 mmHg increase) (1)</td>
<td>Official medical files (1)</td>
</tr>
<tr>
<td>Bendok-iene et al, 2011⁰⁰</td>
<td>Cross-sectional, n = 3 121</td>
<td>Lithuania, 2007 – 2009 (2)</td>
<td>Pregnant women from prenatal care practices (2)</td>
<td>79% (0.5)</td>
<td>Gestational hypertension (≥140 or ≥ 90 mm/Hg) (1)</td>
<td>Measured by physician (1)</td>
</tr>
<tr>
<td>Jones &amp; Tauscher, 1978³³</td>
<td>Ecological (aggregated data), n = 22 5 146</td>
<td>North America, 1970 – 1972 (2)</td>
<td>Births in the population close to an airport (2)</td>
<td>All registered births (2)</td>
<td>Malformations (excluding polydactylia) (1)</td>
<td>Official medical records (1)</td>
</tr>
<tr>
<td>Kurppa et al, 1983⁴¹</td>
<td>Case-control, preliminary results, n = 2 094</td>
<td>Finland, 1976 – 1978 (2)</td>
<td>Mothers exposed to occupational chemicals and noise pollution during pregnancy (2)</td>
<td>95% (2)</td>
<td>Malformations (1)</td>
<td>Official medical records (1)</td>
</tr>
</tbody>
</table>
two studies for which we calculated unadjusted RR, which might explain the discrepancies. The main source of heterogeneity was McDonald et al.\textsuperscript{55} As Croteau et al.\textsuperscript{29} point out, the studies of McDonald et al. compared noise exposed workers to the general population rather than to non-exposed workers, which makes these studies a bit problematic. Moreover, this 19% risk should be interpreted with caution because of the overestimation of the effect that occurs with OR.

In reference to preterm birth, the risk was not significantly higher for women exposed to $\geq 80$ dB (Fig. 2). Pooled RR remained non-significant (1.03 – 1.07, $p > 0.05$) after each study was excluded and the main sources of heterogeneity were the studies of Peoples-Sheps et al.\textsuperscript{45} and Luke et al.\textsuperscript{57} Statistically significant risk for perinatal death was not associated with noise exposure (Fig. 3). It varied considerably remaining non-significant (0.95 – 1.72, $p > 0.05$), and according to sensitivity analysis the positive effect was mostly due to Hartikainen et al.’s results.\textsuperscript{49}

Pooled RR for spontaneous abortion did not reach statistical significance either (1.05 – 1.33, $p > 0.05$) (Fig. 4) and all heterogeneity was due to Hansteen et al.\textsuperscript{65} as its exclusion resulted in $I^2 = 0.00$.

For preeclampsia the variability after excluding individual studies was also considerable (0.93 – 1.23, $p > 0.05$) but significant pooled RR could not be produced (Fig. 5).

Mothers exposed to high noise during pregnancy had an elevated risk (27%) for gestational hypertension (Fig. 6). That effect became non-significant if...
the studies of Nurminen,\textsuperscript{42} Nurminen & Kurppa\textsuperscript{50}, Bendokiene et al.\textsuperscript{70} or Saurel-Cubizolles et al.\textsuperscript{61} were excluded. Nevertheless, we are inclined to accept that noise exposure during pregnancy is associated with higher risk of gestational hypertension, not only because for this outcome the majority of the estimates were either reported as adjusted RR or calculated as RR, thus being conservative, but also because there is strong evidence for the association of environmental noise with hypertension among the general population.\textsuperscript{8,76}

Finally, we found 47\% increased risk for fetal malformations in relation to intrauterine noise exposure (Fig. 7). These studies were completely homogenous and the pooled RR did not change when sensitivity analysis was conducted (1.41 – 1.53, \(p < 0.05\)).

As this is a considerable risk, we took a closer look at this outcome in particular. Out of five studies assessing this outcome, two were reviewed by
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Croteau et al. 29 and three were added by us. The study of Jones & Tauscher 33 which had highest weight was ecological using aggregated data to compare the incidence of congenital abnormalities in two populations – one living close to an airport and exposed to ≥ 90 dB and another one living in the city centre and exposed to lower noise levels. This study had the highest number of cases (n = 225,146) in our meta-analyses, but due to lacking covariates and the problems associated with aggregated data in received 14 out of 18 points for credibility. Moreover, as the authors noted, living close to an airport is associated with various air pollutants, which might be partly responsible for the increased incidence of malformations. Nevertheless, excluding this study controversially raised RR to 50%. The same applies to the other high-weighted study included by us whose exclusion raised the risk to 53%. 41 Kurppa et al.’s study was assigned 18 out of 18 points for credibility. 41 These findings lead us to suggest that calculating RR for these studies is sufficiently conservative as we were mainly concerned with the specificity of the pooled RR. Moreover, the fact that we were not able to compute RR for Zhang et al. 51 and Kurppa et al. 67 should not affect the results because congenital malformation are very rare in human populations (much lower than 10%).

DISCUSSION

KEY FINDINGS

These meta-analyses showed that intrauterine noise exposure is significantly associated with higher risk for small-for-gestational-age, gestational hypertension and congenital abnormalities. In reference to preterm birth, preeclampsia, perinatal death and spontaneous abortion the pooled RR did not permit making such inferences, although for spontaneous abortion and preterm birth it was just failing statistical significance. In comparison to the findings of previous research on the topic, we did not confirm the conclusion of no association of noise exposure with pregnancy or fetal development made by Hohmann et al. 28 The discrepancies might be caused by the differences in included studies and by the methods applied – purely qualitative vs. meta-analysis. On the other hand, the only other identified meta-analysis on the topic found sufficient evidence of association between occupational
noise exposure during pregnancy and giving birth to a small-for-gestational-age child (27%, meta-regression).29 Thus via two different approaches and research teams this effect was confirmed. Croteau et al.29 also suspected an effect on gestational hypertension, spontaneous abortion, preterm birth and preeclampsia, but did not confirm it. Probably the most prominent discordance between findings is the significant risk for congenital malformations estimated in our study, while the available data did not allow Croteau et al.29 to make conclusions about congenital malformations. However, it is biologically plausible since the corticosteroids produced in reaction to noise are toxic to the embryo and since noise intensity of about 80 dB could increase the hematoencephalic barrier’s penetrability.77

STRENGTHS AND LIMITATIONS

This study builds on previous systematic research. We were able to include studies previously not meta-analyzed or discussed and to extract new data from studies which were previously reviewed. Some of these studies reported results for residential noise, which combined with those dealing with occupational noise reveal wider picture of this environmental pollutant. In addition, adjusted RR were calculated where possible which deems our results more conservative and closer to the real effect of noise exposure on pregnancy. However, human error should always be considered given that only one of the authors conducted the statistical tests. Probably the main strength of these meta-analyses is the use of quality effects model to estimate the pooled RR. According to Doi78 the quality effects model should replace the currently used random effects model as it always outperforms it. The fact that we did not include all quality estimates that the study of Croteau et al.29 offered – for example, publication bias, biological plausibility, precision statistic – should not be particularly concerning because the quality effects model requires only that quality scores rank the analyzed studies with respect to deficiencies rather than by fixed function of bias or being a function of quantitatively measured bias.78 In other words, the quality appraisal and scores need not be reflecting the actual credibility or limitations of the studies, as long as they rank them according to their relative strength of evidence in reference to each other. Thus the weights are redistributed away from lesser quality studies. Another issue with this paper might be mixing together OR and RR, but as stated, some of the effect sizes could not be converted to RR. Although our approach for calculating adjusted RR is criticized72, the arguments refer mainly to common outcomes. Combining data from occupational and residential settings might also raise some concerns, because noise effects are dependent on both sound intensity and the frequency spectrum, as well as on the time pattern of exposure and individuals’ activities which are disturbed.79 Finally, the limited access to repository content and the lack of external funding prevented us from reviewing the full texts of some studies, so we had to either rely on previously abstracted data or leave them out of the analyses.

IMPLEMENTATION

The theory that variations in intrauterine environment might affect fetal development is increasingly accepted.23 The results of this study might be used to promote adequate strategies for screening and prevention of noise-related pregnancy adverse outcomes. These inferences will have to be replicated by other meta-analyses and new field studies and, if found to be adequate, hypertension screening programs and prenatal diagnostics will have to be implemented and made priority for women working or dwelling in highly noisy environments. It is true that the industrial development and mechanization of all branches of industry have reduced the number of women working in manufacture, for example, which might be the cause for the limited number of recently published studies assessing these phenomena and their interrelationships. It is also true that this does not apply with full strength to poorer countries with limited advance in industrial technology. Women are undertaking jobs that were previously “the privilege of men” – bus drivers, train engineers, heavy machinery operators, etc. – and this keeps open the question whether they are actually exposed to lower noise levels in comparison to 50 years ago. Moreover, residential noise is constantly rising as a result of urbanization, population growth and modern lifestyle. Factories, traffic, railway and aircraft transportation, which are the major sources of noise in woman’s life, are also producing toxic gases which have distinct impact on fetal development.80 Hence, quantifying the additive effect of noise exposure will yield clearer picture and provide guidance for health promotion and disease prevention in pregnant women, since both noise and air pollution can affect cardiovascular health via different pathways.81
CONCLUSIONS

The results confirm some previous findings regarding a higher risk for small-for-gestational-age. They also highlight the significance of residential and occupational noise exposure for developing gestational hypertension and especially congenital malformations when the mother is exposed to noise levels ≥ 80 dB. These findings will have to be confirmed by new field studies and, if found to be adequate, hypertension screening programs and prenatal diagnostics will have to be implemented and made priority for women working or dwelling in highly noisy environments.

REFERENCES


References truncated due to limitation of references’ number for this type of study. All references are available upon request to the corresponding author or at: https://docs.google.com/document/d/1zA0ZHLAaCxLssn9MIBbMNwO_MbpUgA-4nSaIJ4oYkQ8/edit?usp=sharing.