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Unveiling Optimal Car Alarm's Sound Pressure Level (SPL) for Effective Alerting of Drivers on Locked Children in Cars: Insights from a Physical Survey

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ABSTRACT – *The Child Presence Detection (CPD) system is crucial in alerting drivers of a child locked in the car due to driver negligence resulting in the child death rate due to being locked in a car has increased over the years. The effectiveness of alerting drivers through car alarms depends on the hearing effectiveness of the driver. Previous studies have documented that age group has a critical impact on the effectiveness of hearing in individuals. At the same time, there is no specific standard or framework that underlines the optimal or minimum car alarm Sound Pressure Level (SPL) that is required to effectively alert drivers of a locked child in the car. The main objective of this study was to obtain an optimal SPL for the car alarm that effectively alerts drivers for two different age groups (17-26 years and 27-36 years) through experimental analysis (physical car alarm hearing assessment). It was found that a minimum SPL of the car alarm of 79.841 dBA and 83.179 dBA is required to effectively alert drivers for age group 1 (17-26 years) and age group 2 (27-36 years), respectively. Two mathematical models were constructed through this study to predict the maximum allowable distance and the time before the alarm sound is no longer effective in alerting the drivers. The findings of this study will be useful to regulators and car manufacturers in establishing a framework for determining the optimal SPL of the car alarm for an effective CPD system.*

KEYWORDS: Sound Pressure Level (SPL), Child Presence Detection (CPD) system, car alarm, hearing assessment, age, driver

1. INTRODUCTION

A car alarm is a security system that protects a vehicle from theft or break-in, where it is made up of sensors that detect unwanted access or vehicle tampering, such as breaking windows, unlocking doors, or attempting to start the engine without a key (Azizan, 2015). Another important purpose of car alarms is to detect unattended children that have been locked inside. This mechanism is known as the Child Presence Detection (CPD) system. Children may be left unattended in a car in some cases while a parent or caregiver runs errands or performs other duties (Jawi, 2018; Husain et al., 2020). Hundreds of children die every year from heat stroke after being left in hot cars, often by accident (Zaki et al., 2021). CPD plays a crucial role in preventing the occurrence of these incidents by alerting the driver if a child is left in the vehicle, allowing them to take immediate action and avoid tragedy (Ismail et al., 2019). In addition to preventing accidents and abductions, CPD may give parents and caregivers peace of mind (Hashim et al., 2014).

The death of children related to vehicles has increased over the years. Hot car deaths are a potential danger imposed on children around the world. According to past studies, cars can become dangerously hot even when the ambient temperature is modest. With an outside ambient air temperature of 22°C, the internal vehicle temperature can reach 47.2°C in 60 minutes, with the first 30 minutes accounting for 80% of the temperature increase (NSC, 2022). CPD is a safety technology that helps drivers avoid the repercussions of leaving children in closed, parked automobiles, it detects the presence of a child or pet in the car using a variety of sensors, vehicle-related child death still increases over the year, even after implementing CPD (Kassim, 2018). The problem arises when the alarm alert system (sound pressure level) is not suitable for everyone in different age groups (Ismail et al., 2019).

Past studies have shown that individuals of different genders have different hearing thresholds (a lower hearing threshold means better hearing capacity). Louw et al. (2018) studied the impact of gender on hearing threshold in an experimental investigation with 1,084 respondents (802 female and 282 male) by performing pure tone audiometry screening in an examination room without sound isolation. The authors found no significant relationship with gender in 40.2% of participants who self-reported hearing loss, and 12.5% of participants self-reported hearing loss and failed audiometry evaluation (35 dB HL at 1, 2, and 4 kHz) (Louw et al., 2018). Nikakhlagh et al. (2017) also documented that the gender difference was found to be insignificant at a level of $p < 0.05$ through an experimental study among 72 children (38 boys and 34 girls). In contrast, Hussein et al. (2018) mentioned that gender had a significant effect on the hearing threshold ($p < 0.05$) through an experimental study among 6,424 children (3-6 years) [11]. Moreover, Prodi et al. (2019) documented that girls have better hearing capability (M = 91.8%, SD = 8.3%) than boys (M = 89.6%, SD = 10.1%), although the difference between genders was not statistically significant. Therefore, it can be concluded that gender does not have a critical impact on an individual's hearing threshold when it comes to the effectiveness of alarm-sound hearing.

In contrast to sex, age plays an important role in the hearing threshold. In age-related hearing loss, the patient’s ability to hear sounds and process speech is impaired due to a lack of coordination between the peripheral hearing organs and the brain (Kim & Chung, 2013). Humes et al. (2010) reported that older individuals are subjected to greater hearing loss compared to younger individuals. The experimental study included 202 female and 137 male participants, and the result showed that the partial correlation between age and the gap-detection threshold was 0.03 at 1000 Hz and 0.01 at 3500 Hz, but it was 0.13 and 0.23 for older age at 1000 Hz and 3500 Hz, respectively, indicating that hearing loss is more common in older individual (Humes et al., 2010). Similarly, Wang et al. (2019) discovered that as respondents’ age increases, their hearing threshold increases (hearing sensitivity decreases). In the study, Wang et al. (2019) included 3,754 participants (1,900 males and 1,854 females) aged 18 to 98 years, with pure-tone audiometric thresholds evaluated at frequencies ranging from 0.125 to 8 kHz for each participant. They found the difference in Pure Tone Average (PTA) or the hearing threshold between the age group of 18 and 98 is around 34 dBA for 8kHz audio which shows that the hearing effectiveness drops when the age of a person increases. This finding was consistent with that of Lee et al. (2012), who reported that the hearing threshold increases with increasing age group for audio sound frequency from 5 to 20 kHz in an experimental study involving 352 individuals aged 10 to 65 years old. Another study that validated the effect of age on the hearing threshold was conducted by Park et al. (2016), who used 15,606 respondents (40% male and 59% female) and an age group ranging from 70 to 85 years. As a result, it is determined that the age group greatly impacts the hearing threshold of drivers, with older individuals having poorer hearing capabilities (greater hearing thresholds), implying that car alarm Sound Pressure Level (SPL) should consider the age of older individuals.

The objective of this study was to obtain the optimal alarm SPL in effectively alerting drivers of a child locked in the car concerning the driver’s age group (group 1: 17-26 years; age group 2: 27-36 years). Two mathematical models were established to predict the maximum allowable distance and time before the alarm sound is no longer effective in alerting the drivers. It is expected that the findings from this study can be used to establish a framework for regulatory bodies to set standards on optimal car alarm SPL for car manufacturers in effectively alerting drivers. This research is a collaboration with the Malaysian Institute of Road Safety Research (MIROS) and the New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) (Kassim, 2018; Rosli et al., 2019; Kamaruddin et al., 2021).

2. MATERIALS AND METHODS

2.1 Research Flow Model

Figure 1 shows the flow chart for this research where the measurements were conducted in parallel: car alarm SPL measurement, background noise measurements, and online hearing assessment (online survey). Honda City 2014 and Proton Suprima 2010 were utilized as platforms for this study to obtain the alarm sound. Background noise was measured at Kangar's McDonald's (Perlis) parking lot. Both car alarm sound and background noise were obtained to replicate a realistic car alarm hearing assessment (physical survey). An online hearing assessment was conducted to screen respondents to ensure they had no hearing issues when they joined the physical survey for this research. Once the first three activities were completed, the physical car alarm sound hearing assessment (physical survey) was conducted to obtain the optimal SPL that efficiently alerts the driver for various age groups. The results of the physical survey were analyzed and validated using the ANOVA.

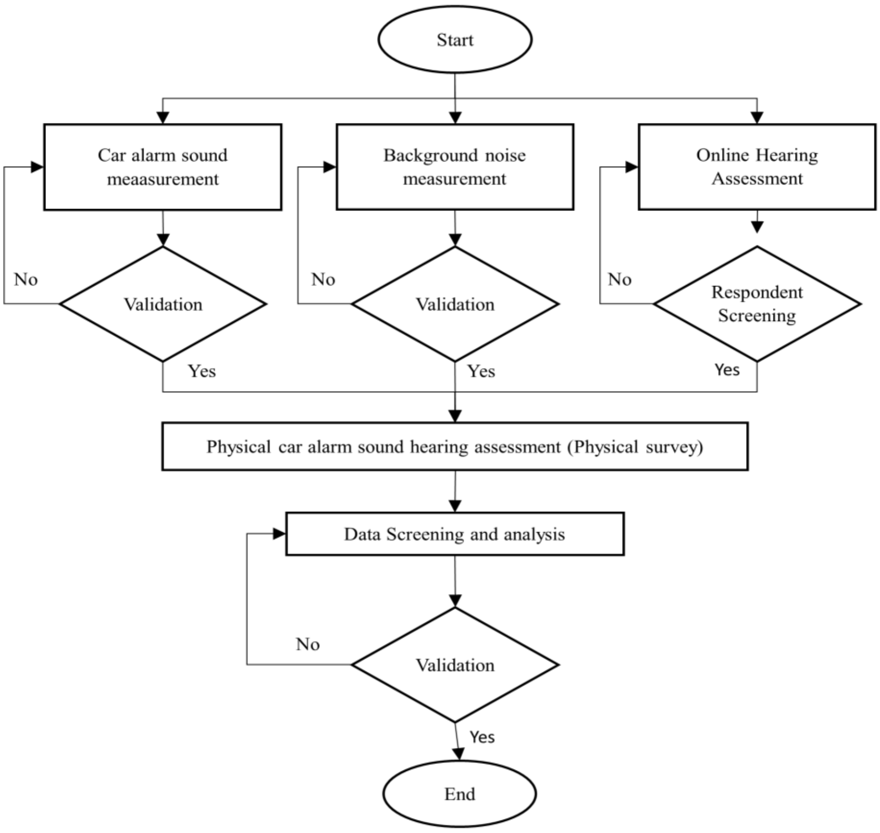

FIGURE 1: Research flowchart

2.2 Car Alarm Sound and Background Noise Measurement

Honda City 2014 was used as the platform to measure the car alarm sound. Background noise was measured and captured at the said parking lot, where the setup is shown in Figure 2. The A-weighted SPL and audio of car alarm sound and background noise were measured using Tenma 72-942 (IEC61672-Type 2) sound level meter (Katalin, 2018; Segaran et al., 2020), and BM800 professional microphone, respectively. The sound measurement was carried out by meeting most of the ISO 3744:2010 standards. The wind speed was checked to be below 5 m/s (Abdullah et al., 2021), and no significant noise interfered with the measurement of the alarm sound. Background noise was measured for two hours; the measurement was taken between 7:00 am to 9:00 am and 5:00 pm to 7:00 pm with 1-minute intervals to obtain the equivalent continuous sound level, LA_{eq} (Halim & Abdullah, 2014; Segaran, 2019; Segaran et al., 2020). The formula of LA_{eq} is shown in Equation (1) where L_i is the A-weighted SPL for each interval (Katalin, 2018; Abdullah et al., 2021).

$$LAeq = 10 \log \sum 10^{(\frac{Li}{10})} \quad (1)$$

FIGURE 2: Sound level meter set up at the parking lot

2.3 Research Respondents

A total of 68 volunteers were recruited through poster and brochure distribution at Universiti Malaysia Perlis (UniMAP) and social media promotions. The volunteers were initially screened using an online survey (hearing assessment) comprised of various components (Table 1) to guarantee that they did not have any hearing difficulties when they participated in the next physical survey.

Based on the online hearing test, 79.4% (54 volunteers) passed and qualified for the physical alarm sound hearing test. The respondents were divided into two age groups: 17-26 and 27-36 (Table 2). As a side note, 17 years old is the minimum legal driving age in Malaysia, according to the Road Transport Department (RTD) (Jawi et al., 2015).

Based on past studies, it was documented that gender showed no significant impact on the hearing threshold among 436 respondents (Nikakhlagh et al., 2017; Louw et al., 2018; Prodi et al., 2019). Therefore, only the effect of the age group on the car alarm hearing effectiveness was focused on in this study.

TABLE 1: Components in the online hearing assessment (https://www.resound.com/en-us/online-hearing-test)

Section	Description
1	General contact details
2	Social lifestyle (related to hearing effectiveness)
3	General hearing assessment
4	Hearing difficulties
5	Online hearing test (resound)

TABLE 2: Classification of research respondents

Age group	Male	Female
17-26	21	10
27-36	20	3

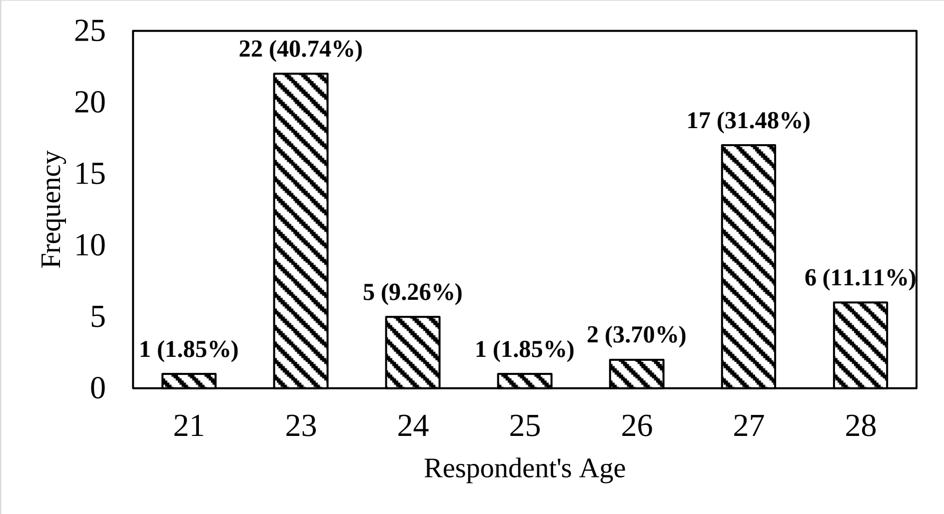

FIGURE 3: Respondents' age

2.4 Physical Car Alarm Hearing Assessment (Physical Survey)

The physical survey was conducted in the Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis (UniMAP), Malaysia (Figure 4). Six speakers were used to conduct the physical survey, in which speaker 1 was to play the alarm sound while the other speakers were to play the recorded background noise. The speakers were placed around the center and separated 1 meter from each other (Vaillancourt et al., 2013; Robin et al., 2020; Brinkmann et al., 2021).

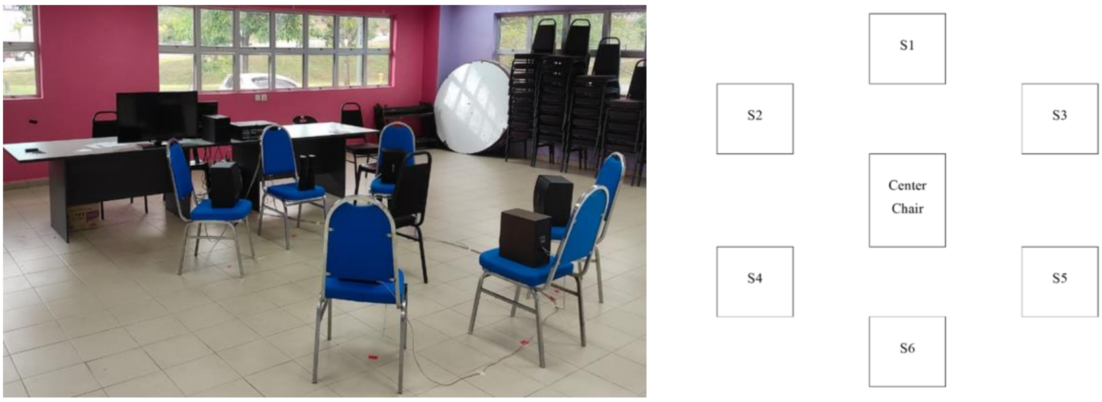

FIGURE 4: Actual setup and floor plan for the physical survey

Figure 5 shows the workflow used for the physical survey involving 54 respondents at UniMAP. When respondents were seated and ready in the center, the evaluation began by playing alarm audio at 90 dBA with constant background noise. The respondents were asked to hear the audio and rated the response option that best corresponds with how well they could hear the audio based on a 5-point Likert scale (Table 3). Respondents would choose from “cannot hear at all” (Score 1) to “can hear very loud and deafening” (Score 5).

The objective of the physical survey was to obtain the SPL value that could be heard loud and clear, which refers to Score 4. Therefore, if the respondent chose Score 3 for the first time, the survey ended. However, if the respondent chose Score 4 or 5, the SPL of alarm audio would be reduced by 2 dBA until they chose Score 3. The minimum SPL value that was on Score 4 would be determined as the optimal alarm SPL that alerts the respondents.

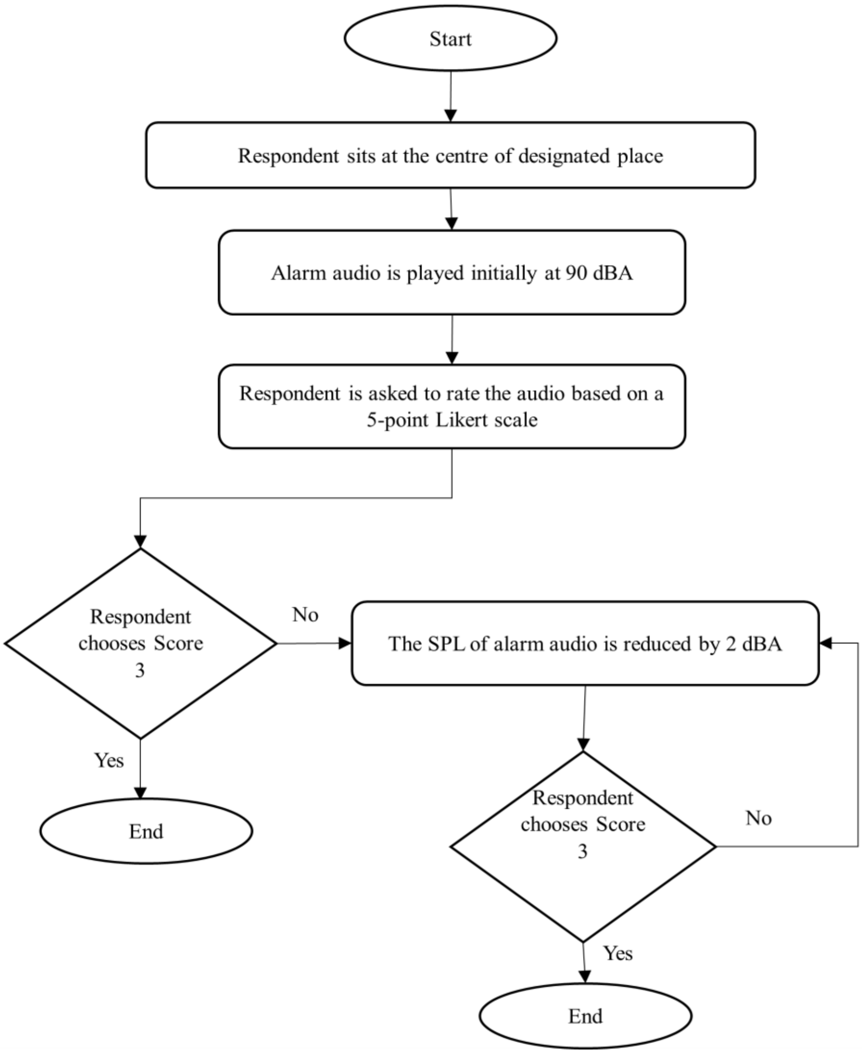

FIGURE 5: Workflow of physical hearing assessment

TABLE 3: 5-point Likert scale used in the physical hearing assessment

Score 1	Score 2	Score 3	Score 4	Score 5
Cannot hear at all	Can hear moderately but not clear	Can hear moderately and clear	Can hear loud and clear	Can hear very loud and deafening

Once the data was obtained from the physical survey, the significance of the age group to the hearing effectiveness of the respondents was analyzed using Analysis of Variance (ANOVA), and the p-value was made sure to be lower than 0.05. Previous studies used ANOVA or SPSS software to examine data obtained from hearing assessments. In 2018, Louw et al. (2018) found that hearing loss increased significantly with age groups, with a p-value of 0.498. Prodi et al. (2019) analyzed the accuracy of data using ANOVA, and it was documented that gender contributes to a minimal factor on speech intelligibility (SI) with a p-value of 0.001. Hussein et al. (2018) used binomial logistic regression in the study of hearing screening for children. It was mentioned that gender has a minor effect on hearing, with the p-value obtained less than 0.01. Humes et al. (2010) studied the significance of the age group to the hearing threshold. It was mentioned that the age group has a significant effect on hearing, where increasing age lowers hearing capability with a p-value less than 0.001. Wang et al. (2019) studied the hearing threshold of individuals in Zhejiang, China, and documented significant differences among age groups for both ears at all frequencies, where the higher age group had the worst hearing with a p-value less than 0.05. Park et al. (2016) documented that age significantly affects the hearing threshold, with a p-value obtained less than 0.05. This shows that ANOVA is a common method used to analyze the accuracy of data for hearing assessment where a p-value of lower than 0.05 is considered accurate.

3. RESULTS AND DISCUSSION

3.1 Car Alarm Sound Measurement

The car alarm SPL (Honda City 2014) was measured and recorded using Tenma 72-942 (SPL meter) and BM800 professional microphone. The measurements were taken at a fixed vertical distance of 1.5 m from the ground (Segaran et al., 2020; Abdullah et al., 2021), while the horizontal distance from the car's front bumper varied, as indicated in Table 4 and Figure 6. To prevent contact between the SPL meter and the car, a minimum distance of 0.1 m was maintained. The alarm audio characteristics, including the frequency and the time interval between frequencies, were obtained using REW and Audacity software, as shown in Table 5.

TABLE 1: Car alarm SPL versus distance

Vertical	Horizontal	SPL (dBA)
1.5	0.1	69.2
1.5	1	68.4
1.5	2	67.8
1.5	3	67.2

TABLE 2: Car alarm audio characteristics

Characteristics	Value
Minimum frequency (Hz)	2823 Hz
Maximum frequency (Hz)	3473 Hz
The delay between frequencies (s)	0.170 s

Figure 6 depicts the data, which follows a quadratic equation as illustrated in Equation (2), where d represents the distance of the measured alarm SPL from the source.

$$SPL = 0.0712d^2 - 0.8999d + 69.273 \quad (2)$$

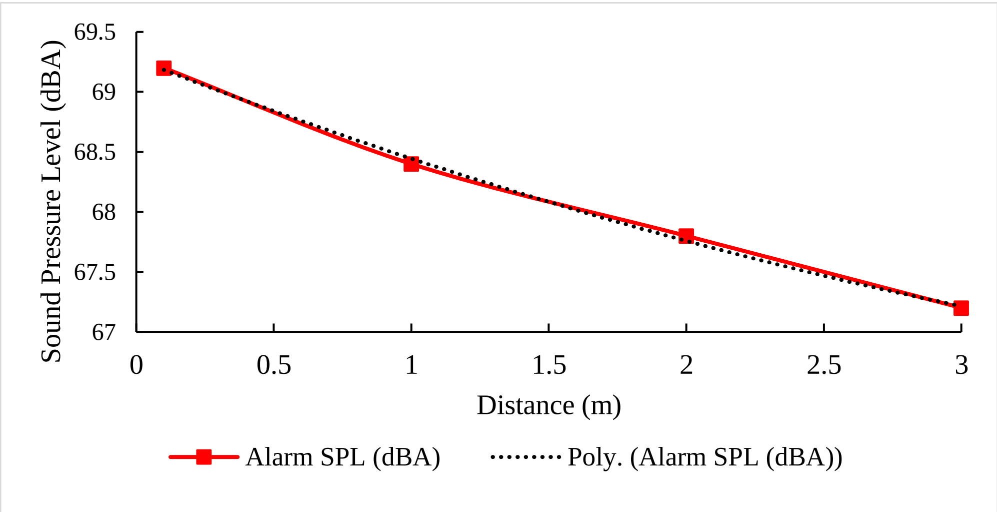

FIGURE 6: Car alarm's Sound Pressure Level (SPL) versus distance

To explore the relationship between the SPL of the car alarm and distance over a wider range, the car alarm sound was replicated using sets of speakers in UniMAP's lab. The alarm SPL at the source was increased to a maximum value of 107 dBA due to limitations imposed by the speakers. It is worth noting that previous studies have documented the possibility of hearing loss with continuous exposure to loud sounds exceeding 110 dBA for up to 2 minutes (Seidman & Standring, 2010; National Center for Environmental Health; 2022). Therefore, a maximum car alarm's SPL of 107 dBA from the source is considered acceptable, considering the potential risk of hearing loss. A generic mathematical model (theoretical formula) that describes the relationship between the distance from the source and the received SPL (sound attenuation – inverse square law) was established in previous research as shown in Equation (3) and Figure 7 (WKC, 2021).

$$SPL_2 = SPL_1 - 20\log\left(\frac{d_2}{d_1}\right) \tag{3}$$

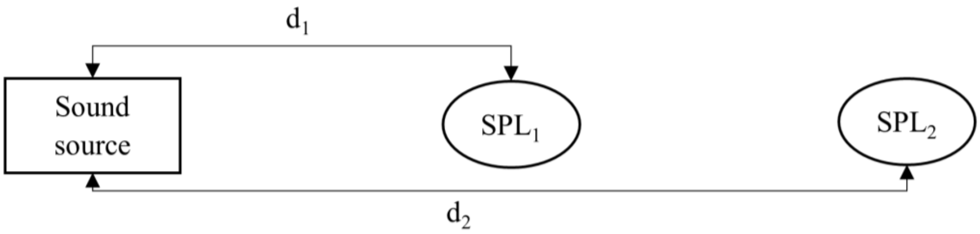

FIGURE 7: Visual representation of the generic theoretical formula

By examining Figure 8, it is evident that the experimental SPL values for the car alarm, plotted against the distance from the source, closely align with the data derived from the theoretical formula. To plot the SPL using the theoretical formula based on Equation (3), fixed values SPL_1 and d1 were employed, specifically 98.5 dBA and 1 m, respectively. The maximum percentage of error between the experimental and the theoretical data is 12.57% at 20 m. Considering the experimental conditions, which involved minimal background noise interference and the absence of a soundproof environment, this percentage of error falls within an acceptable range.

Furthermore, it is important to note that the generic theoretical formula established in previous research does not account for a critical factor: the frequency of the sound. Equation (4), a mathematical model, represented in Equation (4), was developed to depict the relationship between SPL and distance for the specific car alarm sound selected in this study. The SPL_2 is the sound pressure level of the alarm sound measured with respect to the distance, d from the alarm sound source. Table 4 and Table 5 provide details about the characteristics of the alarm sound. The mathematical model yields an R-squared value of 0.9743, indicating a strong correlation. The comparison between the SPL values obtained from the mathematical model and the experimental results revealed a maximum percentage of error of 4.24%, affirming the reliability of the formula. Consequently, this mathematical model can effectively predict the SPL versus distance, specifically for the alarm sound used for this research.

$$SPL_2 = -7.169\ln(d) + 103.89 \tag{4}$$

The general shape of the equal loudness curve illustrates that our ears exhibit the highest sensitivity to sounds within the mid-frequency range, typically around 1,000 to 4,000 Hz when presented at moderate sound pressure levels. It is noteworthy that as the sound pressure level either decreases or increases, the equal loudness curve shifts, indicating that different frequencies necessitate varying sound pressure levels to be perceived as equally loud. When sound pressure levels are low, our ears demonstrate reduced sensitivity to both low and high frequencies in comparison to mid-range frequencies. Conversely, as the sound pressure level rises, the equal loudness curve becomes flatter, signifying an increased sensitivity to low and high frequencies (ISO 226:2003) (Parmanen, 2012). Therefore, it becomes evident that the generic model depicted in Equation (3) cannot be universally applied to all ranges of sound frequencies.

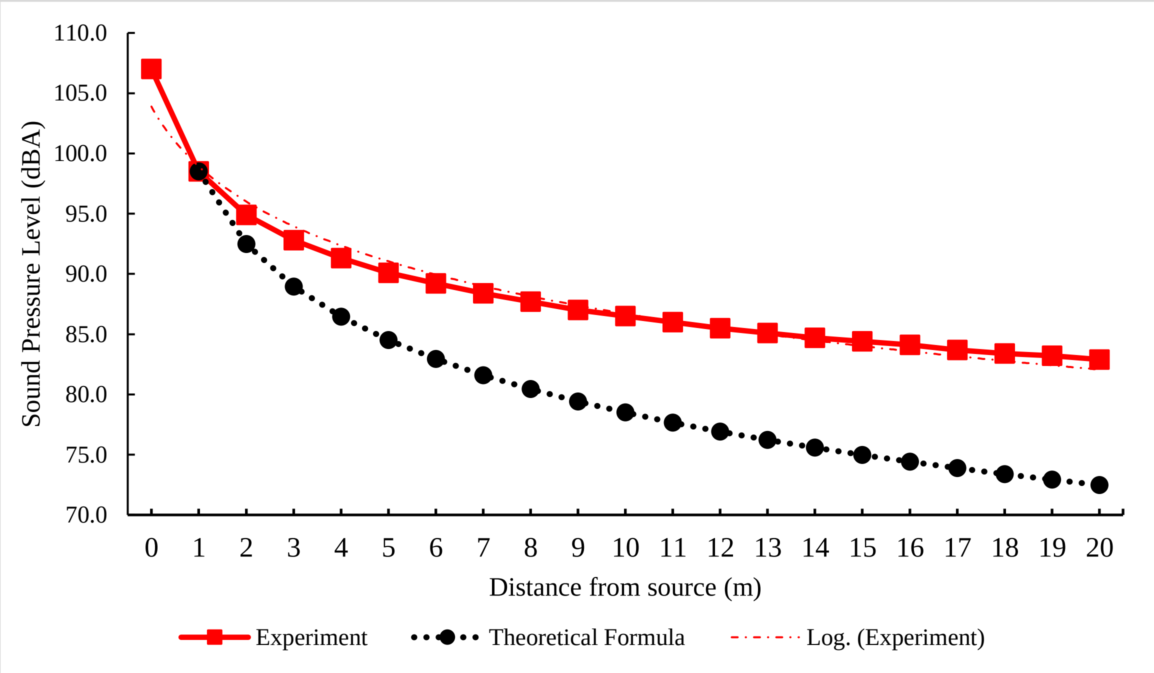

FIGURE 8: Comparison of experimental result and theoretical formula for SPL versus distance from the source

3.2 Background Noise Measurement

Background noise measurements were conducted using a similar method to the one employed for measuring the car alarm sound. The measurements took place at the said parking lot and were performed during two distinct time periods: morning (7:00 am to 9:00 am) and evening (5:00 pm to 7:00 pm). Figure 9 and Figure 10 present the sound pressure levels (SPL) of the background noise, as recorded by a sound level meter, over a period of a 2-hour period with 1-minute intervals for both the morning and evening periods. The observed SPL ranges from 50 to 75 dBA in the morning and 60 to 75 dBA in the evening. To calculate the Equivalent Continuous Sound Level (L_{eq}) for various time intervals, Equation (1) was utilized, and the results are summarized in Table 6 and Table 7. The selection of a 2-hour duration for Leq aligns with the previous studies. Consequently, a maximum L_{eq} value of 68.75 dBA was recorded for the evening period, and this value was subsequently employed as the fixed variable representing the background noise during the physical survey.

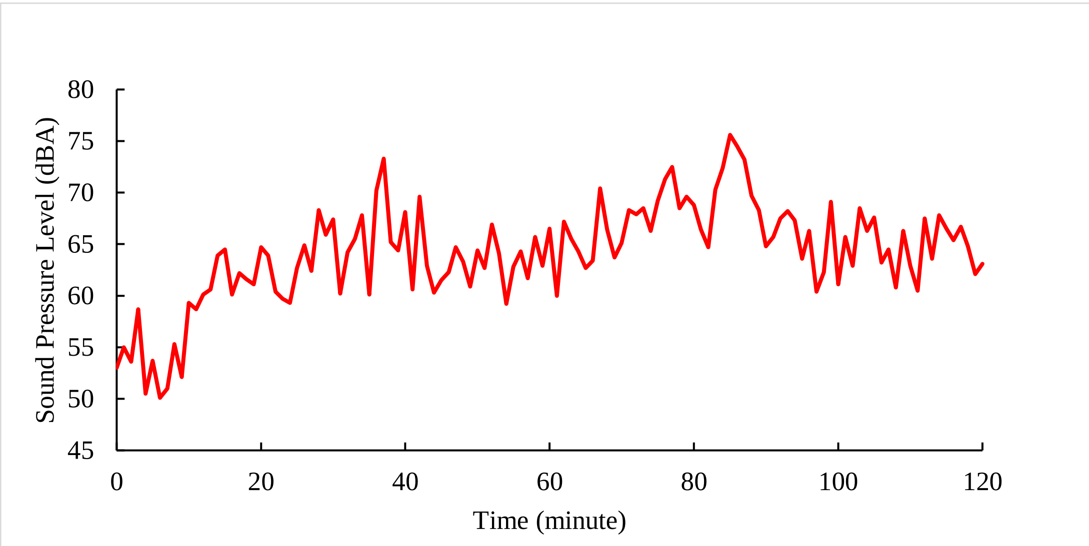

FIGURE 9: Background noise SPL versus time (morning)

TABLE 6: Equivalent continuous sound level (L_{eq}) for background noise at the parking lot (morning)

Time (min)	L_{eq}
15	58.81
30	62.04
45	64.31
60	64.22
75	64.84
90	66.73
105	66.66
120	66.48

TABLE 7: Equivalent continuous sound level (Leq) for background noise at the parking lot (evening)

Time (min)	L_{eq}
15	67.81
30	68.30
45	69.57
60	69.48
75	69.28
90	69.17
105	68.95
120	68.75

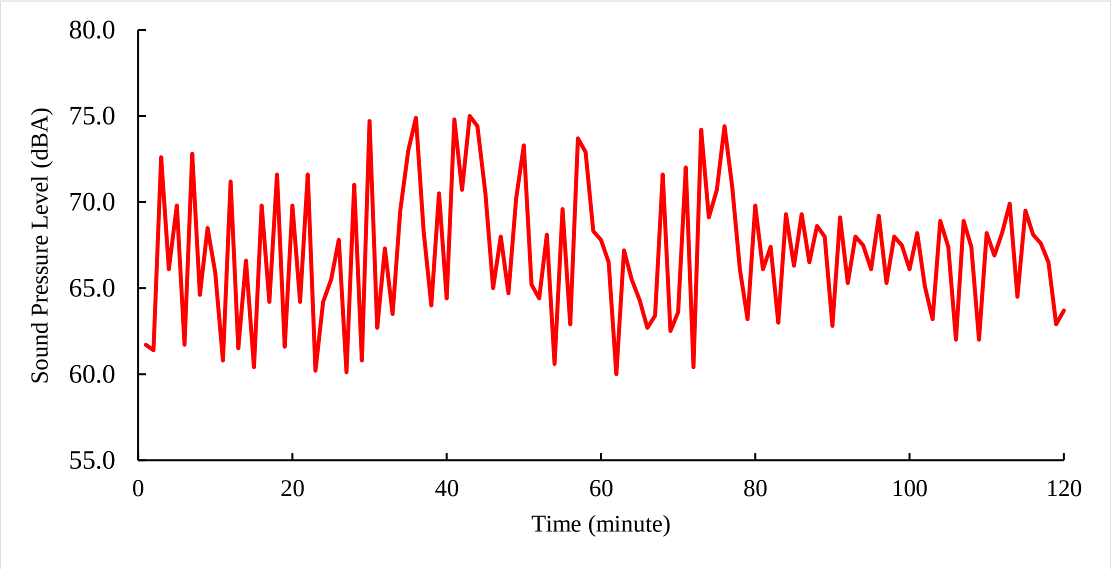

FIGURE 10: Background noise SPL versus time (evening)

3.3 Physical Car Alarm Hearing Assessment (Physical Survey)

Among the 54 respondents, the median age was 25.02 years and 24.1% (n = Humes 13) of them were female. The respondents were grouped into two different categories as shown in Table 8. Age group 1 (17-26 years) comprised 57.41% (n = 31) of the respondents, while age group 2 (27–23 years) consisted of 42.6% (n = 23) of the respondents. To determine the minimum SPL required for the respondents to hear the alarm sound loud and clear (Score 4), a one-way ANOVA analysis was conducted at 95% of confidence level. The analysis revealed that age group 1 requires a mean SPL of

75.452 dBA to ensure effective auditory perception, whereas age group 2 necessitates a mean SPL of 81.565 dBA. These values represent the minimum SPL thresholds for the respective age groups. Additionally, the upper boundary for ensuring effective driver alertness (Score 4) was determined to be 79.841 dBA for age group 1 and 83.179 dBA for age group 2.

Figure 11 shows an interval plot depicting the chosen SPL (Score 4) by respondents in relation to their age group, as determined through ANOVA variance analysis. Notably, the plot demonstrates an increasing trend in the mean SPL required to perceive the alarm sound as loud and clear as the age group advances (Humes et al., 2010; Wang et al., 2019; Smith et al., 2021). To further visualize this trend, Figure 12 and Figure 13 present individual value plots and box plots of the chosen SPL (Score 4) by respondents according to their age group. From these figures, it is evident that the first age group (17-26 years) exhibits a wider range of chosen SPL (Score 4) compared to the second age group (27-36 years). This observation can be attributed to the larger variation in age within the first age group, as indicated in Figure 3.

TABLE 8: Analysis of means of optimal SPL

Age Group	n	Mean	Standard Deviation	95% CI
17-26	31	78.452	4.523	(77.062, 79.841)
27-36	23	81.565	2.694	(79.952, 83.179)

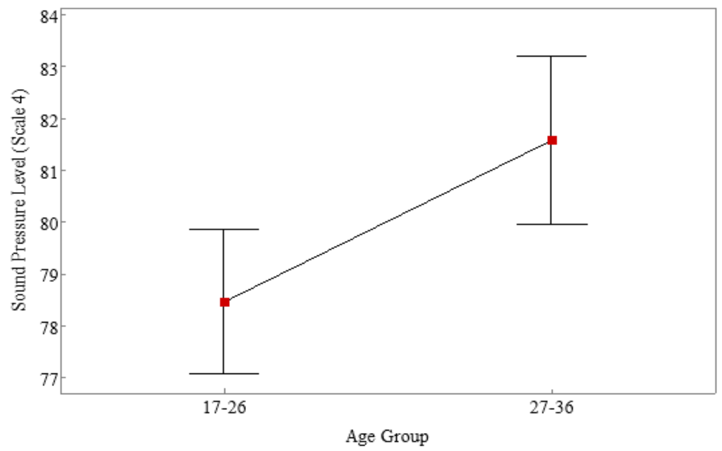

FIGURE 11: Interval Plot of SPL (Score 4) versus age group

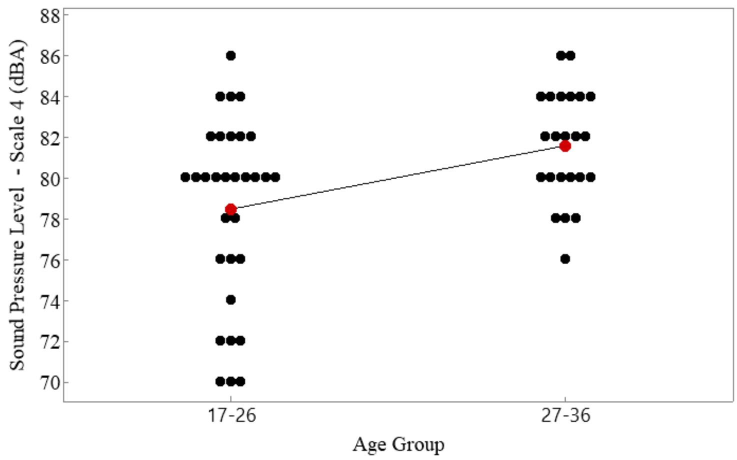

FIGURE 12: Individual value plot of SPL (Score 4) versus age group

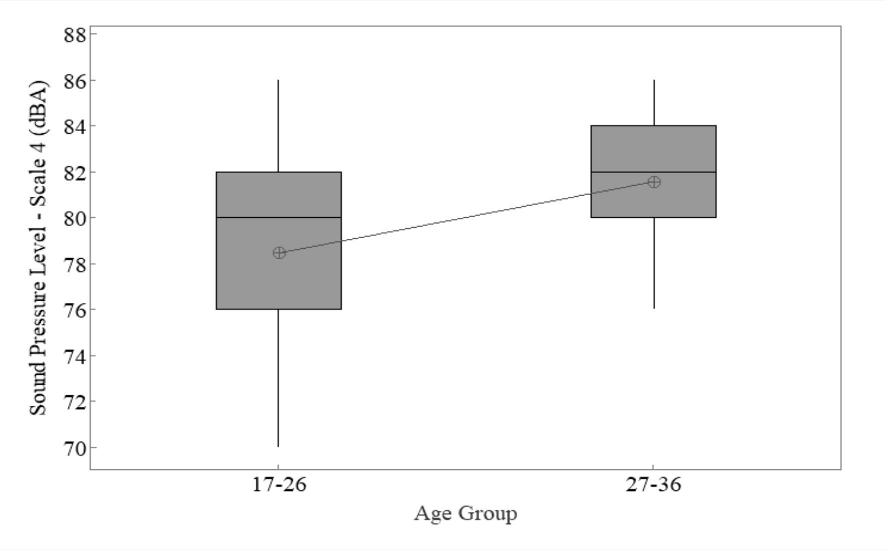

FIGURE 13: Boxplot of SPL (Score 4) versus age group

The chosen SPL (Score 4) by respondents in the 2 different age groups was found to be significantly different from each other (p-value = 0.005 < 0.05), establishing the validity and reliability of the research findings. According to Table 4 and Figure 6, the current car alarm SPL for the Honda City 2014 model measured at 69.2 dBA when positioned 0.1 m from the front hood. However, this existing car alarm SPL falls below the minimum threshold required to effectively alert drivers, as indicated by the results of this study (existing alarm SPL: 69.2 dBA < minimum SPL required to alert drivers: 79.841 for age group 1 and 83.179 for age group 2). Hence, based on this research, it can be concluded that the optimal SPL values for alerting drivers about a locked child in the car are 79.841 dBA for age group 1 and 83.179 for age group 2.

TABLE 9: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Age Group	1	128.0	128.00	8.61	0.005
Error	52	773.3	14.87		
Total	53	901.3			

3.4 Elucidation of Optimal SPL in Alerting Drivers and the Distance Travelled Away from the Car

The SPL of the alarm sound diminishes as distance increases, as demonstrated in Figure 8. By correlating the optimal SPL that effectively alerts drivers for each age group with the derived mathematical model presented in Equation (3), we can determine the precise distance at which the alarm sound ceases to be efficient in alerting the drivers, as indicated in Equation (5). Equation (5) is derived from Equation (4), where SPL_O represents the optimal or minimum SPL of the alarm sound required for effective alertness, and d_{max} represents the maximum distance that the alarm sound can travel from its source before it becomes ineffective in alerting drivers. It is assumed that the SPL of the alarm sound at the source is 107 dBA.

$$d_{max} = e^{-(\frac{SPL_O - 103.89}{7.169})} \tag{5}$$

Equation (6) is further derived based on Equation (5) by considering the alarm sound SPL from the source, SPL_s as one of the manipulated variable.

$$d_{max} = \left[e^{-(\frac{SPL_O - 103.89}{7.169})} \right] - \left[e^{-(\frac{SPL_S - 103.89}{7.169})} \right] \quad (6)$$

The maximum distance (d_{max}) at which the alarm sound ceases to effectively alert drivers can be correlated with the average walking speed of individuals in Malaysia, which is 1.16 m/s (Abdullah et al., 2021). This relationship is shown in Equation (7), where t_{max} represents the maximum available time before the alarm should be triggered through the CPD sensing system if a child is locked in the car.

$$t_{max} = \frac{\left[e^{-(\frac{SPL_O - 103.89}{7.169})} \right] - \left[e^{-(\frac{SPL_S - 103.89}{7.169})} \right]}{1.16} \quad (7)$$

Based on results obtained from the physical survey conducted in this study, Equation (6) and Equation (7) can be utilized to determine the maximum distance (d_{max}) and maximum time (t_{max}) for the alarm sound characteristics used in this study, as shown in Table 10. From the table, it is evident that the alarm sound is effective in alerting drivers up to a maximum distance of 28.63 m and 17.97 m for age groups 1 and 2 respectively. Consequently, the alarm sound should be triggered within 24.68 seconds and 15.49 seconds to effectively alert drivers of a locked child in the car for age group 1 and age group 2, respectively.

TABLE 10: Mapping of maximum distance that alerts the driver effectively

SPL (dBA)	Maximum Distance before the alarm SPL effectively alerts the drivers (m)	Time to trigger alarm sound (s)
79.841 (Age Group 1)	28.63	24.68
83.179 (Age Group 2)	17.97	15.49

The mathematical models developed in this study have significant practical applications for car manufacturers and regulatory bodies in setting standards for car alarms. However, it is important to note that these models are limited in scope and can only be applied to the specific car alarm characteristics examined in this study, as outlined in Tables 4 and 5.

4. CONCLUSION

In conclusion, this study has provided valuable insights that can serve as a guideline and framework for regulatory bodies and car manufacturers in developing an effective Child Presence Detection (CPD) system that alerts drivers about locked children in cars. The findings indicate that a minimum car alarm SPL of 79.841 dBA and 83.179 dBA is necessary to effectively alert drivers in age group 1 (17-26 years) and age group 2 (27-36 years), respectively. The ANOVA variance analysis revealed that the optimal SPL for alerting drivers differs significantly between the age groups (p-value < 0.05). Two mathematical models were developed with a maximum error of 4.24% to predict the maximum allowable distance and time before the alarm sound becomes ineffective in alerting drivers. These models can be instrumental in guiding regulatory bodies to establish standards or frameworks for determining the optimal car alarm SPL in implementing an efficient CPD system. However, it is important to note that this study focuses on a specific type of car alarm SPL with fixed frequencies and time intervals. To further enhance the applicability of the models, future studies should consider incorporating frequencies and time intervals of the car alarm as variables and refining the mathematical models established in this research. By expanding the scope of the investigation, future studies can provide additional insights into optimizing the effectiveness of CPD systems and contributing to ensuring the safety of children in cars.

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