**Elucidation of Multi-Tone Car Alarm Sound Pressure Level: Evaluating the Effectiveness of Car Alarm for Elder Adults**

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**Abstract.** The Child Presence Detection (CPD) system plays a pivotal role in notifying drivers when a child is inadvertently left in a vehicle, a situation that has tragically led to an increase in child mortality rates over time. The system's efficacy is contingent upon the driver's auditory acuity, which previous research has shown to be significantly influenced by age. Despite this, there is currently no established standard or guideline specifying a car alarm's minimum or optimal sound pressure level (SPL) necessary to notify drivers of a child trapped inside the vehicle effectively. This research aimed to ascertain the most suitable SPL for a vehicle alarm system that would efficiently notify drivers of two separate age categories (37-46 years and 47 years and older). This was achieved through experimental analysis, specifically by physically assessing the car alarm's auditory perception. The results indicated that to effectively alert drivers in the first age group (37-46 years), a minimum car alarm SPL of 83.6 dBA is required. In comparison, for the second age group (47 years and above), a minimum SPL of 85.5 dBA is necessary. These findings could provide valuable insights for supervisory bodies and automobile manufacturers in developing an outline to determine the optimum SPL of a car alarm, thereby enhancing the effectiveness of the CPD system.

1. **Introduction**

A vehicle protection system, often called a car alarm, is an essential deterrent against unauthorized intrusion or theft. This system is equipped with sensors capable of detecting unlawful attempts to access or interfere with the vehicle, as cited by Azizan *et al*. [1]. In addition, these alarm systems are integral to the Child Presence Detection (CPD) mechanism, which aims to prevent children from being accidentally trapped inside vehicles. Instances where children are unintentionally left unattended in a car while a parent or caregiver is engaged in errands or other activities have been reported by authors in [2][3]. Regrettably, many children die from heatstroke each year because of being inadvertently left in overheated vehicles, as noted by Zaki *et al*. [4]. As stated by Hashim *et al*. [5], the CPD system is key in averting such incidents by notifying the parents if their child has been left in the car, letting them act quickly and preventing a potential disaster. Beyond its role in preventing accidents and possible kidnappings, the CPD system can also offer parents and caregivers a sense of security and reassurance.

The number of vehicle-related child fatalities has been on the rise in recent years, with heatstroke from being left in hot cars representing a significant global threat to children. Prior research suggests that the interior of a vehicle can reach hazardous temperatures even in moderate external conditions, as reported by McLaren *et al.* [6]. CPD is a safety feature designed to reduce the risks of leaving children in parked vehicles. It uses a variety of sensors to detect the presence of a child or pet inside the car. However, despite the implementation of CPD, the rate of vehicle-related child fatalities continues to increase each year, as mentioned by Kassim *et al.* [7]. One of the challenges is the effectiveness of the alarm alert system. The sound pressure level of the alarm may not be appropriate for individuals of different age groups, thereby limiting its effectiveness in preventing such incidents, as stated by Ismail *et al*. [8].

Research has demonstrated that someone of different genders exhibits distinct hearing thresholds, wherein a lower threshold signifies superior auditory ability. An experimental study conducted by Louw *et al*. [9] on 1,084 participants (802 females and 282 males) using pure tone audiometry screening in a non-sound isolated examination room established no noteworthy relationship between gender and hearing loss in 38.9% of contributors who self-disclosed hearing loss. A similar study by Nikakhlagh et al. [10] involving 72 children (38 boys and 34 girls) also found the gender difference to be statistically insignificant at a p < 0.05 level. However, a contrasting finding was reported by Hussein et al.[11] in a study involving 6,424 children aged 3-6 years, where gender was found to affect the hearing threshold (p < 0.05) significantly. Moreover, Prodi *et al*. [12] reported that girls demonstrated better auditory capability than boys, even though the deviation was not arithmetically substantial. As a result, it can be presumed that gender does not play a crucial role in a person's hearing threshold, especially regarding the effectiveness of alarm-sound perception.

Age, as opposed to gender, plays a pivotal role in determining an individual's auditory threshold. Auditory degradation associated with age is marked by a diminished capacity to perceive sounds and understand speech, as stated by Kim *et al.* [13]. Humes *et al.* [14] found that older individuals suffer more severe hearing loss than their younger counterparts. Their study assessed hearing thresholds at 500, 1414, and 4000 Hz. The findings reveal that middle-aged and older adults exhibited significantly poorer performance than young adults across all measures of threshold sensitivity, indicating a higher degree of hearing loss in older adults. Wang *et al.* [15] also observed that aging is associated with an increased auditory threshold (i.e., a decrease in auditory sensitivity). Their study encompassed 3,754 participants aged between 20 and 90 years. The results show that speech-frequency and high-frequency hearing loss incidence was 27.9% and 42.9%, respectively. This finding is consistent with that of Lee *et al. [*16], who stated that the hearing threshold increases for all frequencies as age increases. *Hwi et al*. [17] further confirmed the correlation between the hearing threshold level, frequency, and age in a rigorously screened population. Hence, it can be inferred that age significantly influences the auditory threshold, with older individuals demonstrating compromised auditory capabilities. This suggests that the SPL of car alarms should consider the age of older individuals.

The purpose of this investigation was to identify the optimum SPL of a car alarm that can effectively alert drivers when a child is locked inside the vehicle, taking into account the age group of the driver (group 1: 37-46 years; group 2: 47 years and above). The expected results of this study could serve as a foundation for supervisory bodies to define principles for the optimal SPL of car alarms, thereby assisting car manufacturers in improving the efficacy of their alert systems for drivers. This research was carried out in partnership with the Malaysian Institute of Road Safety Research (MIROS) and the New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP). The authors employ this collaborative methodology in [7,18].

1. **Methodology** 
   1. *Research Flow Model*

Figure 1 presents a diagrammatic illustration of the research methodology, encompassing concurrent processes: measuring the vehicle alarm's SPL, evaluating ambient sound, and conducting an online hearing assessment (online survey). The vehicles employed in this study were two cars with different types of alarms, which functioned as the sources of the car alarm sound. The ambient sound was obtained in the heavy traffic area. The car and ambient sound were gathered to create a realistic physical alarm hearing assessment environment. A hearing test was performed to pre-screen participants, ensuring they were free from hearing impairments before participating in the physical survey. After completing the initial three tasks, a physical survey was executed to ascertain the optimal SPL of the car alarm to alert drivers of different age groups effectively. The data derived from the physical survey was subsequently examined and validated using Analysis of Variance (ANOVA).

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**Figure 1.** Flow diagram of the experimental study.

* 1. *Vehicle Alarm and Ambient Sound Assessment*

Table 1 shows the vehicle that was used in the experiment. Model A was utilized as the test vehicle for measuring the vehicle alarm sound. The ambient sound was documented at the designated location. The A-weighted SPL and audio of the vehicle alarm sound and ambient noise were recorded utilizing a Type 2 sound level meter and a BM800 professional microphone, respectively. The authors also employ this methodology in [19,20]. The sound measurement procedure largely complies with the ISO 3744:2010 standards. The wind speed was confirmed to be under 5 m/s, adhering to the guideline set by Segaran *et al.* [20], thereby ensuring no significant interference from noise during the computation of the alarm sound. The ambient noise was recorded for 2 hours at intervals of 1 minute to acquire the constant ambient noise level, Leq. Segaran *et al.* [20] also implemented this ambient noise measurement method. The equation for Leq is given in Equation (1). Several authors [20,21] have also utilized this equation.

**Table 1.** Type of vehicle alarm specification

|  |  |  |  |
| --- | --- | --- | --- |
| Model | Vehicle type | Production year | Alarm type |
| A | Honda City | 2014 | Multi-tone |
| B | Proton Suprima | 2013 | Single-tone |

(1)

Where Li represents the A-weighted SPL for each intervening period.

* 1. *Research Respondents*

A cohort of 51 individuals was assembled for participation in a study at Universiti Utara Malaysia (UUM). An initial screening was conducted through an online survey, which included a hearing assessment. This preliminary evaluation ensured that the participants exhibited no auditory impairments before participating in the subsequent physical survey.

As per the online auditory examination results, 35.3% of the participants, which equates to 51 volunteers, met the necessary criteria to proceed to the physical alarm sound hearing test. The participant pool was then segregated into two distinct age brackets: those aged 37-46 and those aged 47 and above, as detailed in Table 2. Jawi *et al.* [21] also used the same method.

Previous research by several authors [9]–[11] has indicated that gender does not significantly influence the hearing threshold, as evidenced by a study involving 436 participants. Consequently, this study concentrated solely on the impact of age groups on the effectiveness of vehicle alarm audibility.

**Table 2**. Categorization of Research Participant

|  |  |  |  |
| --- | --- | --- | --- |
| Age group | Age range | Male | Female |
| A | 37-46 | 9 | 11 |
| B | 47 and above | 14 | 17 |

* 1. *Physical Hearing Evaluation*

A The survey employed six speakers, with speaker 1 assigned for the emission of the alarm sound, while the remaining speakers were responsible for the playback of recorded ambient noise. These speakers were strategically arranged around a central point, exactly 1 meter apart, a method also implemented by the authors in [22]–[24].

Figure 2 delineates the methodology adopted for the acoustic survey carried out with 51 participants at UUM. The assessment began with the participants positioned and prepared at the central location, followed by an alarm audio playback at a sound pressure level of 90 dBA amidst consistent ambient noise. Participants were directed to listen to the audio and choose the response option on a Likert scale (refer to Table 3) that best represented their auditory perception of the audio. The options spanned from "Inaudible" (Point I) to "Perceptible at extremely high, potentially harmful volume levels" (Point V).

The acoustic survey aimed to determine SPL that could be distinctly perceived, corresponding to Point IV on the Likert scale. As a result, if a participant selected Point III during the initial assessment, the survey was concluded. However, if a participant selected Point IV or V, the SPL of the alarm audio was decreased by 2 dBA until the participant selected Point III, the lowest SPL value corresponding to Point IV was recognized as the ideal alarm SPL for alerting the participants.



**Figure 2.** Flow diagram of hearing survey

**Table 3**. Likert scale used in the hearing survey

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Point I | Point II | Point III | Point IV | Point V |
| Unable to perceive any sound. | Can perceive sound to a certain extent, but not distinctly. | Able to hear with a moderate level of clarity. | Able to perceive sound clearly and at a high volume. | Able to hear sounds that are extremely loud and potentially ear-splitting. |

Post the collection of data from the acoustic survey, the impact of age demographics on auditory proficiency using Analysis of Variance (ANOVA), ensuring a p-value less than 0.05 for statistical significance. Prior research has employed ANOVA or SPSS software for data analysis in auditory assessments. For instance, Louw *et al.* [9] detected a significant increase in hearing loss in advancing age groups, substantiated by a p-value lower than 0.05. Prodi *et al.* [12] utilized ANOVA for data accuracy analysis, noting that gender had a negligible effect on speech intelligence (SI), as indicated by a p-value of 0.488. Humes *et al.* [14] applied binomial logistic regression in their study on pediatric audiometry evaluation, noting a minor gender-based effect on hearing with a p-value more than 0.5. Hussein *et al.* [11] examined the relevance of age demographics to the hearing threshold, asserting that increasing age negatively impacts auditory capability, supported by a p-value less than 0.001. Wang *et al.* [25] studied the audiometry thresholds of individuals with different age groups, recording major differences between age groups, with the older demographic demonstrating inadequate hearing, as indicated by a p-value less than 0.05. Hwi *et al.* [17] reported a significant effect of age on hearing loss, corroborated by a p-value less than 0.05. These studies collectively suggest that ANOVA is a prevalent method for data accuracy analysis in auditory assessments, with a p-value less than 0.05 indicative of accuracy.

1. **Results**

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* 1. *Vehicle Alarm Sound Assessment*

The SPL assessments were performed at a uniform vertical elevation 1.5 m from the ground. A minimum gap of 0.1 m was preserved to prevent interaction between the SPL meter and the vehicle. The auditory attributes of the alarm, encompassing frequency and frequency intervals, were scrutinized using REW and Audacity software.

To investigate the correlation between the SPL of the vehicle alarm and distance across an extensive scale, the alarm was recreated using a speaker in a laboratory (Mechanical Design Lab, Universiti Malaysia Perlis). The SPL of the alarm was escalated to 110 dBA, constrained by the speakers' capabilities. It is vital to acknowledge that prior studies, as referenced by Seidman *et al.* [26], have proposed the potential of auditory damage from exposure to noise surpassing 120 dBA for more than 1 minute. Therefore, a maximum SPL of 110 dBA from the source of the vehicle alarm is deemed safe, considering the potential hazard of hearing loss.

Figure 3 shows a strong correlation between the measured SPL data for the vehicle alarm, plotted to the distance from the source, and the simulated sound value. The most substantial discrepancy between the experimental and simulated data is 7.1% at a distance of 1 m. This error margin is considered adequate given the experimental environment, which incorporated the least disruption from ambient noise and the lack of an acoustically insulated environment.

**Figure 3.** Comparison of experimental and simulation results for SPL from distance 0 to 10m

* 1. *Ambient Sound Measurement*

The methodology for assessing ambient noise paralleled the vehicle alarm sound measurement technique. The evaluations were conducted at the specified parking area and the specified periods, which correspond with the peak hours in Malaysia, as stated by Segaran *et al.* [20]. The ambient noise SPL was recorded using a type 2 sound level meter. The Equivalent Continuous Sound Level (Leq) was computed using Equation (1). The maximum Leq value observed was 68.8 dBA, which was then utilized as the constant variable representing the ambient noise in the hearing survey.

* 1. *Alarm Hearing Assessment (Physical Survey)*

The study comprised 51 participants with a median age of 46.47 years. Females constituted 54.9% (n = 28) of the sample. Table 4 categorizes the participants into age groups. Age group B (those above 47) represented 60.78% (n = 31) of the sample, while age group A (those between 37 and 46) accounted for 39.22% (n = 20). A one-way ANOVA analysis determined the lowest SPL required for participants to perceive a loud, clear sound (Point IV). The results indicated that the average SPL necessary for effective auditory perception was 83.6 dBA for age group A and 85.5 dBA for age group B. These data show the minimal SPL for each age group. Furthermore, the upper limit for ensuring effective driver alertness (Point IV) was identified as 84.9 dBA for age group A and 86.6 dBA for age group B.

The ANOVA variance analysis is visualized in Figure 4, which displays an interval plot of the respondents' chosen SPL (Point IV) to their age group. The graphic corroborates the findings of other researchers [14,25,27] by illustrating a significant upward trend in the mean SPL required for loud and clear alarm sound perception as the age group increases.

**Table 4**. Optimal SPL Analysis

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Age Group | n | Mean | Standard Deviation | 95% CI |
| 37-46 | 20 | 83.6 | 1.903 | (82.2, 84.9) |
| 47 and above | 31 | 85.5 | 1.434 | (84.4, 86.6) |

A graph of age group

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**Figure 4.** Comparison of Point IV SPL and age group

As indicated in Table 5, the SPL chosen by participants from two different age groups showed significant differences (p-value = 0.000 < 0.05), thereby validating the consistency and reliability of the study's results. The existing vehicle alarm SPL of Model A was measured at 69.2 dBA at a distance of 0.1m from the front hood. However, this study found that this SPL is below the minimum threshold necessary to alert drivers adequately.

**Table 5**. Analysis of Variance

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
| Age Group | 1 | 46.15 | 46.150 | 17.33 | 0.000 |
| Error | 49 | 130.48 | 2.663 |  |  |
| Total | 50 | 176.63 |  |  |  |

Table 6 displays the results of the survey for different types of alarms. The data clearly shows that the multi-tone alarm of Model A was the favored option for 35 out of the 51 participants. On the other hand, the single-tone alarm of the Model B was chosen by merely 18 participants. The multi-tone alarm, with a preference weightage of 68.63%, exhibits greater dependability in terms of alertness compared to the single-tone alarm. This implies that the multi-tone alarm system is more proficient in alerting individuals, boosting reliability. In contrast, the single-tone alarm system has a lower preference rate, signifying a potential scope for enhancement in its alertness capability. In conclusion, the multi-tone alarm system seems to be a more dependable and favored option among the participants, offering valuable insights for designing and implementing future alarm systems.

**Table 6.** Survey for different types of alarm

|  |  |  |
| --- | --- | --- |
| Age group | Model A | Model B |
| A | 14 | 6 |
| B | 21 | 10 |
| Total | 35 | 16 |

1. **Conclusion**

In conclusion, this research offers crucial insights that can assist regulatory agencies and automobile manufacturers in creating an efficient CPD system to alert drivers when children are accidentally left in vehicles. The data suggests that for effective alerting, a minimum vehicle alarm SPL of 83.6 dBA is necessary for the first age group (37-46 years) and 85.5 dBA for the second age group (47 years and above). The ANOVA results showed a significant difference (p-value < 0.05) in the optimal SPL for alerting drivers across different age groups. It should be noted that this research is focused on a particular vehicle alarm SPL. Future research should consider incorporating the vehicle alarm frequencies and time intervals as variables. By expanding the scope of the research, future studies can offer further understanding into enhancing CPD systems, thereby improving vehicle safety for children.

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