# Analysis of Influencing Factors of Auditory Warning Signals' Perceived Urgency and Reaction Time

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**Abstract.** The auditory warning is one of the most important information in cockpit. To study the effects of auditory warnings to human capability of receiving information, this paper describes the test about the effects of various warning features on the information receiving performance of the testers. Testers in the laboratory environment finish the mission for determination of 24 warning tones combined by two volumes (65 dB (A), 75 dB (A)), three frequencies (700 Hz, 1,200 Hz, 1,700 Hz), and four inter-onset intervals (100, 150, 300 and 600 ms). This test considers the perceived urgency judgment and reaction time of the tester as the study data that experiences the comparative analysis and variance analysis after being paired. The study results indicate that the sound volume influences the perceived urgency judgment significantly ($p < 0.05$) and impacts the reaction time greatly ($p < 0.01$). Sound frequencies also effect the perceived urgency judgment significantly ($p < 0.05$) and so do the inter-onset intervals in both the perceived urgency judgment and reaction time ($p < 0.01$). In conclusion, the greater the volume is, the higher the frequency is, the shorter the inter-onset interval is, and the higher the perceived urgency is while the greater the volume is, the shorter the inter-onset interval is, and the shorter the reaction time becomes.

**Keywords:** Auditory warning · Cockpit · Volumes · Frequencies · Inter-onset interval

## 1 Introduction

A great deal of researches indicate that auditory warnings can improve the alertness of operators to abnormalities and assist them in quick identification of hazards and in shortening operators' reaction time [1–3]. Auditory warning has been widely applied in many fields, especially in the field of aviation [4–6]. Cockpit audio warning system through the different auditory warning caused by the pilot's attention to quickly


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identify, and make the right response. However, the auditory warning tone will make it difficult for pilots to follow, resulting in information overload, and prone to human error, resulting in the occurrence of major accidents, especially in emergency situations. A lot of auditory warnings to the pilot's mental load and physiological load presents a serious challenge [6, 7]. Therefore, the optimum design of cockpit auditory warning is ergonomics concerns an important issue.

Auditory warnings of different acoustic properties will have an impact on people's alarms perception. Wogalter et al. [1] have demonstrated that voice warning signals can shorten the operators' reaction time to abnormalities through the research. United States military standard NASA-STD-3000 [8] and MIL-STD-1472F [9] only the auditory warning has developed several standards in principle, but did not address specific property requirements of the auditory warning. By now, many researchers have studied the effects of sound volume, frequency, rhythm, and inter-onset intervals, based on properties of these items, to human perceived urgency judgment and reaction time. However, there are also differences between the research content and the research results of different scholars. Suied et al. [10] have verified the effects of auditory warning properties to warning receiving and they have demonstrated the effects of sound inter-onset intervals of respective 100 ms and 300 ms and sound laws to the reaction time and perceived urgency feel. In the test, the reaction time is measured and the result indicates a quicker response from a smaller pulse separation and that the easier the attention is paid, the more irregular the signal is Haas and other researchers [3] tested and studied the perceived urgency and objective reaction time by means of pure auditory warnings with sound inter-onset intervals of 150 ms and 300 ms, sound intensities of 65 dBC and 79 dBC and with various pulse modes. Results of the perceived urgency tests show that with sound selected, the smaller the inter-onset interval is, the greater the volume is, and the higher the perceived urgency becomes while results of the response tests indicate that the volume influences the reaction time but the inter-onset interval does not. In addition, the test results show a correlation between the perceived response and reaction time, that is, the higher the perceived urgency is, the quicker the response gets. Bodendörfer [11] through the experimental study on the acoustic properties of the four (volume and frequency, pulse frequency, pulse inter-onset interval) to tone alarms perception confirm the effect. Found that reducing the frequency and pulse time of two consecutive pulses to increase workers' perception confirmed. Perception of sound frequency and number of people recognize and have no effect. Chinese scholar Li et al. [12] have studied the hearing judgment performance under different frequencies and constant volume and ordered the pure auditory warning signals of 6 frequencies under the volume of 60 dB by priority.

Aiming at the effects of properties of warning tones to perceived urgency judgment and reaction time, tests are designed in this paper to study effects of perceived urgency judgment and reaction time by selecting three different acoustic properties of sound volume, frequency and inter-onset interval, expecting to provide theoretical basis and standards for design and selection of auditory warnings in the cockpit.

## 2 Method

### 2.1 Conditions of Subjects

13 subjects are involved in the test aging from 20 to 25 years old without mental or sleep disorders. Moreover, subjects should not participate in similar tests previously.

### 2.2 Test Equipment and Environment

Tests should be conducted indoors and the free sound field should be selected. The sound pressure level at subjects' auricles should be 43 dB (A). The software Cool-pro 2.0 is selected to simulate the warning tones and Experiment Builder is used to program the tests. Programs automatically stimulate the subjects with sound information and record the responses.

### 2.3 Test Design

Tests mainly focus on the effects of different acoustic properties of auditory warnings to subjects. Therefore, for the test, the information receiving response and perceived urgency judgment serve as dependent variables while the sound volume, frequency and inter-onset interval are considered as the independent variables.

For volumes, based on the research findings and related standards [8, 9], generally the main frequency band of all main components of hearing warning signals should be at least 20 dB(A) higher than the noise level whereas in quiet environment, that of the hearing attention signal should be within 50 dB(A) $\sim$ 70 dB(A). Because the background noise level in the test field is 43 dB(A), two volumes of 65 dB(A) and 75 dB(A) are selected for the test.

For frequencies, reference standards, the fundamental tone frequency of the warnings should within 700 Hz and 1,700 Hz. For the purpose of this test and in combination with results of various preliminary tests, the test frequency has been determined to be respectively 700 Hz, 1,200 Hz, and 1,700 Hz.

For inter-onset intervals, in light of studies by Clara Suied et al. [3], human responses experience obvious differences to warning tones with inter-onset intervals of 100 ms and 300 ms ($p < 0.05$). With similar design selected, and inter-onset interval selection ranges enlarged and re-partitioned, this test considers four levels of pulse separation, which are 100 ms, 150 ms, 300 ms, and 600 ms (Table 1).

**Table 1.** Summary of test factors and levels

| Factor | Level |
|---|---|
| Volume | 65 dB, 75 dB |
| Frequency | 700 Hz, 1,200 Hz, 1,700 Hz |
| Inter-onset interval | 100 ms, 150 ms, 300 ms, 600 ms |

### 2.4 Test Process

Three different levels are combined in this test, generating totally 24 simulated warning tones, among which, two of which are paired in a group randomly (sequence distinguished), creating totally 552 comparative sound groups (24 × 23). In order to obtain more accurate data, because subjects need to stay focused, 552 groups are divided into 24 large test teams for independent test. 23 pairs of sounds are involved in each large team and the former 12 pairs are grouped while the latter 11 pairs are grouped. It is required a ten-minute rest be set for each large team and 2 min for each small group. Therefore, the whole test may take approximately 2 h.

Specific implementations of the test are as follows:

1. Subjects sit in front of computer and adjust their sitting attitude and seat height to allow their ears to be at the desired position.
2. Start the test program and a black dot appears at the screen center to concentrate the subject. After 1 s ∼ 2 s random waiting, the first simulated warning tone plays. The subjects need to press the button as quickly as possible and an OK on the screen indicates the valid operation.
3. Subsequently, a circle appears on the screen center and the second simulated warning tone plays as per the identical requirement.
4. After each test, compare the perceived urgency to two simulated warning tones and proceed to the next test after the assessment.
5. Repeat steps 2 to 4 until all 522 tests are finished and test the next subject.

## 3 Results

### 3.1 Analysis on Results of Perceived Urgency Judgment

**Comparison of paired data.** During the tests, total 13 subjects judge each pair of simulated warning tones subjectively, select the tone of higher urgency that they consider and record it. As for no order for sound pairing, one pair of sounds is judged for twice and the test statistics are made for 26 subjects. The perceived urgency to all warning tones is determined after the pairing comparative analysis of statistic data as shown in Table 2. The smaller the perceived urgency value is, the less the urgency to the simulated warning tone is. Positive and negative marks in the results only indicate the magnitude without other meanings.

**Analysis on main effect and interactive actions of influence factors.** By virtue of the investigation of volume, frequency and inter-onset interval of the audio waning signal and of the effects of interactive actions among these three factors to human perceived urgency judgment, the volume, frequency and inter-onset interval as well as the variance of the interactive action are obtained following the calculation and analysis of the relative urgency parameters treated by the pairing comparative method by means of ANOVA as shown in Table 3.

**Table 2.** Perceived urgency value to different simulated warning tones

| Volume: 65 dB | Inter-onset interval | | | |
|---|---|---|---|---|
| Frequency | 100 ms | 150 ms | 300 ms | 600 ms |
| 700 Hz | 0.0755 | −0.3642 | −0.9786 | −2.0191 |
| 1,200 Hz | 0.8452 | 0.2759 | −0.3286 | −0.8942 |
| 1,700 Hz | 0.4461 | 0.0168 | −0.5652 | −1.2516 |
| Volume: 75 dB | Inter-onset interval | | | |
| Frequency | 100 ms | 150 ms | 300 ms | 600 ms |
| 700 Hz | 0.5603 | 0.2111 | −0.4323 | −0.9991 |
| 1,200 Hz | 1.4866 | 0.8392 | 0.1642 | −0.2846 |
| 1,700 Hz | 1.8554 | 1.0201 | 0.3463 | −0.1898 |

**Table 3.** ANOVA table with F-values and significance for perceived urgency

| Perceived urgency | F | P |
|---|---|---|
| Volume | 288.943 | 0.000 |
| Frequency | 70.922 | 0.000 |
| Inter-onset interval | 236.167 | 0.000 |
| Volume × frequency | 0.569 | 0.594 |
| Volume × inter-onset interval | 2.373 | 0.169 |
| Frequency × inter-onset interval | 0.552 | 0.756 |

Following conclusion is obtained based on Table 2:

1. Within selected sound volume range, main effect of volumes should be significant ($F = 288.943$, $p < 0.01$) thus understanding that the volume of pure warning tones influences the perceived urgency judgment significantly.
2. Within selected frequency range, the main effect of sound frequency is obvious ($F = 70.922$, $P < 0.01$) thus knowing that the sound frequency of pure warning tone impacts perceived urgency judgment significantly.
3. Within selected inter-onset interval range, the main effect of sound inter-onset interval is obvious ($F = 236.176$, $P < 0.01$) thus knowing that the sound inter-onset interval of pure warning tone impacts perceived urgency judgment significantly.
4. Because the interactive actions between volume, frequency and inter-onset interval are not significant, it is known that the interactive actions between these factors do not impact the perceived urgency judgment significantly.

**Comparison of distinctions of main effects of different influence factors.** In light of the variance analysis on different levels among the three factors, it is demonstrated that the sound volume, frequency, and inter-onset interval impacts the perceived urgency judgment significantly and that the sound inter-onset interval influences the reaction time much. Figures 1, 2 and 3 show the main effect values of volume and inter-onset interval to perceived urgency judgment. As the sound volume increases, the perceived urgency judgment to sounds ascends but descends with longer sound inter-onset interval.

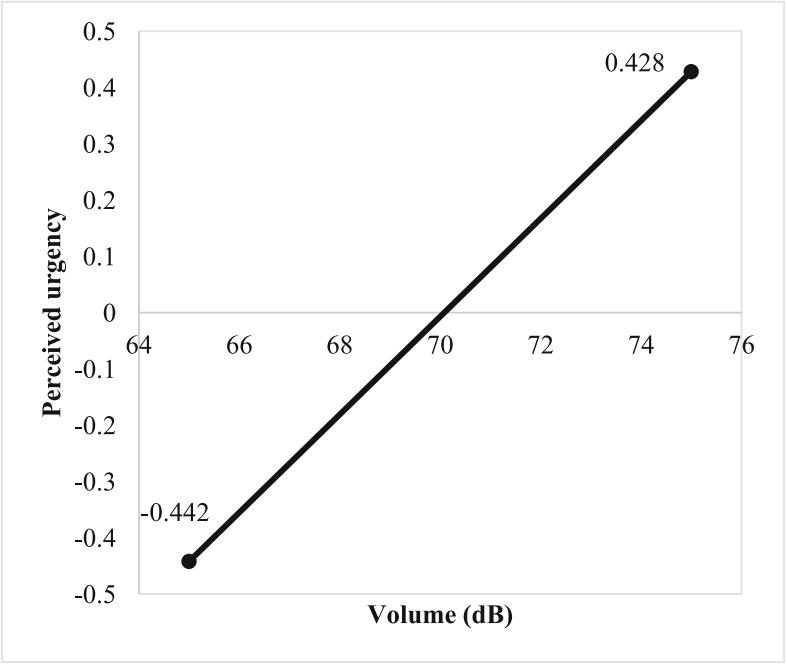


**Fig. 1.** Main effect value of volume to perceived urgency

### 3.2 Analysis on Reaction Time Results Process

**Preprocessing of test data.** Totally 14,352 data are acquired. To ensure correct reaction time and prevent test results from interference by limit values, abnormal data beyond $\pm$ 3 mean square deviation are eliminated under each special condition, leaving effective 13,965 data totally.

**Analysis on main effects and interactive actions of influence factors.** By virtue of the investigation of volume, frequency and inter-onset interval of the audio waning signal and of the effects of interactive actions among these three factors to human perceived urgency judgment, the volume, frequency and inter-onset interval as well as the variance table (Table 4) of the interactive actions are obtained following the calculation and analysis of the relative urgency parameters treated by the pairing comparative method by means of ANOVA.

Following conclusions are obtained based on Table 3:

1. Within selected sound volume range, main effects of volumes should be significant ($F = 5.597$, $0.01 < p<0.05$) thus understanding that the volume of pure warning tones influences the perceived urgency judgment significantly.

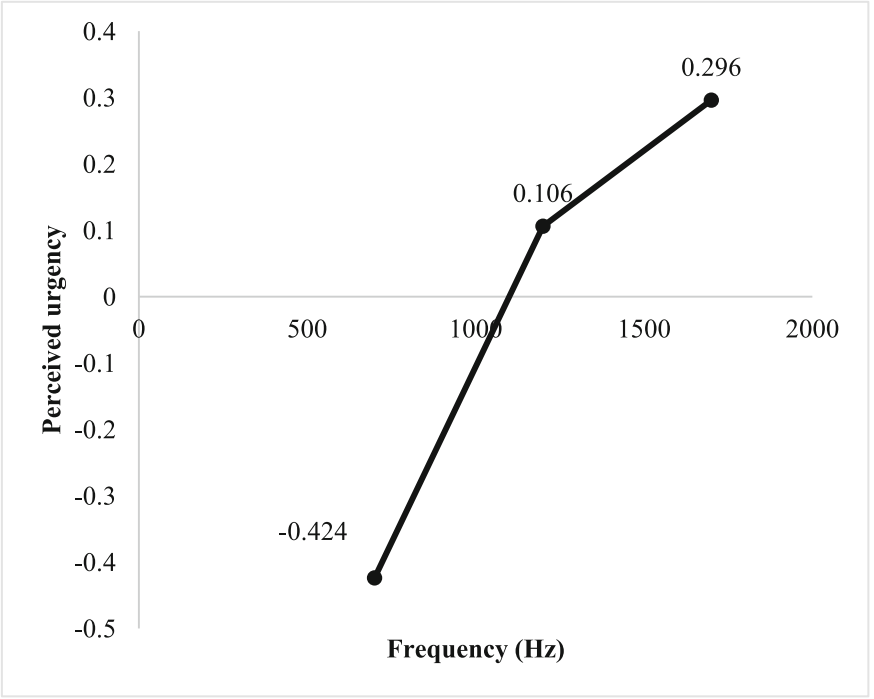


**Fig. 2.** Main effect value of frequency to perceived urgency

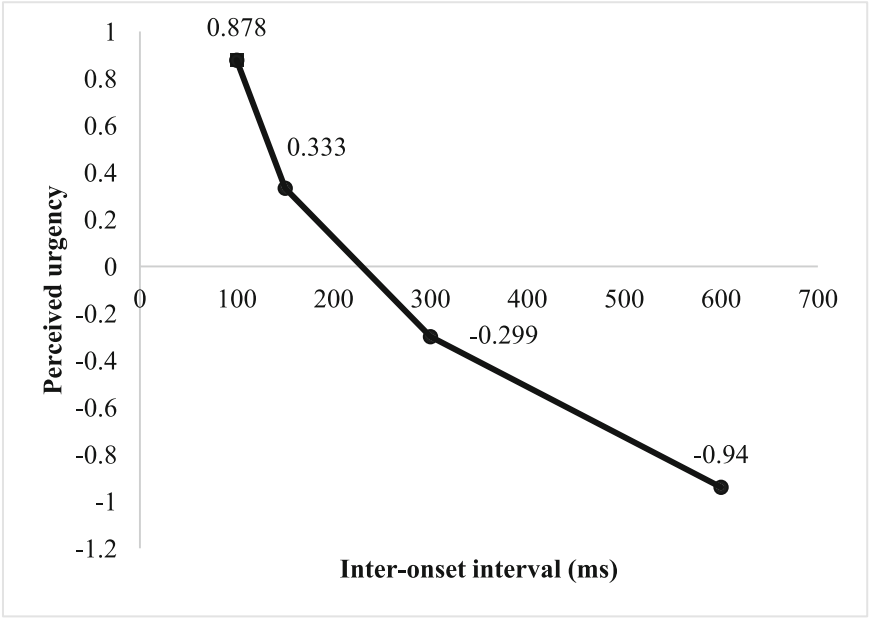


**Fig. 3.** Main effect value of inter-onset interval to perceived urgency

**Table 4.** ANOVA table with F-values and significance for reaction time

| Reaction Time | F | P |
|---|---|---|
| Volume | 5.597 | 0.030 |
| Frequency | 2.331 | 0.127 |
| Inter-onset interval | 47.573 | 0.000 |
| Volume × frequency | 3.443 | 0.101 |
| Volume × inter-onset interval | 14.240 | 0.004 |
| Frequency × inter-onset interval | 4.239 | 0.051 |

2. Within selected frequency range, the main effect of sound frequency is obvious ($F = 2.31$, $P > 0.05$) thus knowing that the sound frequency of pure warning tone impacts perceived urgency judgment significantly.
3. Within selected inter-onset interval range, the main effect of sound inter-onset interval is obvious ($F = 47.573$, $P < 0.01$) thus knowing that the sound inter-onset interval of pure warning tone impacts perceived urgency judgment significantly.
4. Because the interactive actions between volume and inter-onset interval are significant, it is known that the interactive actions between volume, frequency and inter-onset interval impact the perceived urgency judgment significantly.

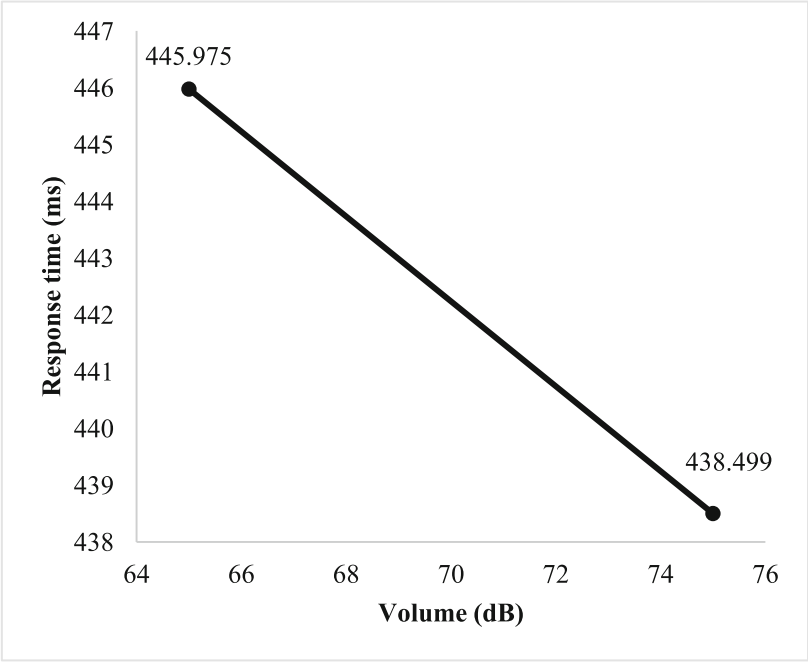


**Fig. 4.** Main effect value of volume to reaction time

**Comparison of distinctions of main effect values of different influence factors.** In accordance with variance analysis on different levels among the three factors, it is demonstrated that the sound volume impacts the reaction time significantly while the sound inter-onset interval does the reaction time more significantly. Figures 4 and 5 show the main effect values of volume and inter-onset interval to reaction time. As the sound volume increases, the response slows but quickens with longer sound inter-onset interval.

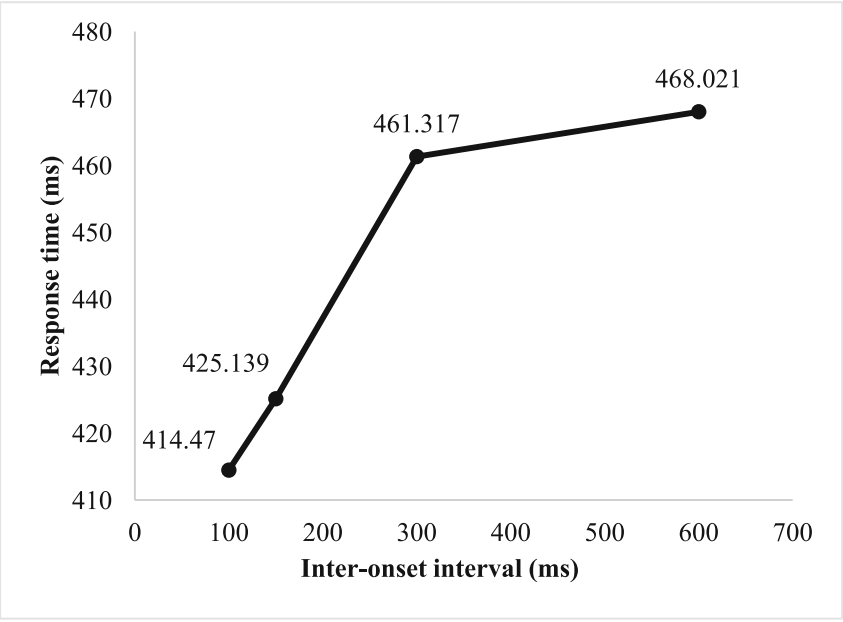


**Fig. 5.** Main effect value of inter-onset interval to reaction time

### 3.3 Relationship Between Perceived Urgency and Reaction Time

Through correlation analysis on perceived urgency values and mean reaction time to 24 warning tones using the Spearman model, the perceived urgency and reaction time are correlative very significantly ($r = 0.611$, $p < 0.01$).

## 4 Discussion

Sound volumes influence the perceived urgency judgment very significantly ($F = 288.943$, $P < 0.01$), which means different volumes have conspicuous differences (see Fig. 1) but affects the reaction time significantly ($F = 5.597$, $0.01 < P < 0.05$) (see Fig. 4), indicating the differences of perceived urgency judgment are small by comparison. The reason is that the perceived urgency feel is more sensitive than

reaction time to the sound volume within a selected range, generating more intensive change and more significant effect.

Sound frequencies impact the perceived urgency judgment very significantly. As the frequency gets higher, the perceived urgency ascends as well yet the effect degrades gradually (see Fig. 2). On the contrary, frequencies hardly affect the reaction time significantly, which is caused by the easier change of perceived urgency due to frequency change within a selected range, thus influencing the reaction time not that much. In other words, the perceived urgency judgment is more compromising to the frequencies than the reaction time.

Hellier [13] has found that the perceived urgency judgment is subject to the consistent effect of sound inter-onset intervals. Bodendörfer [11] also proved via tests that two continuous pulse duration can improve the operators' perception affirmation. In this test, various inter-onset intervals are selected for study to prove the more significant effects of inter-onset intervals to perceived urgency judgment. In addition, with longer inter-onset intervals, the perceived urgency drops continuously and the effect extent of inter-onset intervals to perceived urgency judgment decreases (see Fig. 3).

With inter-onset interval prolongs, the perceived urgency drops continuously and the effect extent of inter-onset intervals to the perceived urgency judgment de-creases (see Fig. 3). This means the change within a short inter-onset interval impacts the perceived urgency judgment more tremendously.

For relationship between warning tone inter-onset interval and reaction time, Haas thinks that the inter-onset interval of sound pulse impacts nothing of the reaction time and Suied et al. [10] discovers that smaller pulse inter-onset interval causes quicker response. Via this test, inter-onset intervals of sound pulses impact the reaction time very significantly by observing the acquired RT data (see Fig. 5) and the RT and inter-onset intervals increase in a linear relation within an inter-onset interval between 100 ms and 300 ms. However, beyond 300 ms, the reaction time ascends obviously slowly. The reason of the difference between them may be:

1. Perceived urgency judgment is more sensitive than reaction time at an inter-onset interval between 100 ms and 300 ms, causing obvious change and more significant effect.
2. A critical point exists for the inter-onset interval effect to human response, once which is exceeded, the inter-onset interval effect to human reaction time drops. For this test, the critical point is 300 ms. Zones between 300 ms and 600 ms can be further divided for subsequent tests to search for a more accurate critical point.

In conclusion, from proceeding analysis, perceived urgency judgment is superior to the reaction time in terms of sensitivity within selected ranges for sound volume, frequency and inter-onset interval. Follow-up tests will concentrate on the relationship between the sensitivity of both objects and applicable scope in detail.

## 5 Conclusion

This paper describes the study of effects of various volumes, frequencies and inter-onset intervals to human perceived urgency judgment and reaction time. The test results indicate as follows:

1. Sound volumes impact perceived urgency judgment very significantly and affect the reaction time obviously. As the volume rises, the perceived urgency increases as well yet the reaction time drops.
2. Sound frequencies influence the perceived urgency judgment significantly. As the frequency gets higher, the perceived urgency rises as well; however, frequencies hardly impacts the reaction time obviously.
3. Sound inter-onset intervals affect the perceived urgency judgment and reaction time very significantly. As the inter-onset interval is prolonged, the perceived urgency drops and the reaction time increases with a greater acceleration at inter-onset interval before 300 ms and slows down at an inter-onset interval beyond 300 ms.

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