Effect of sound pressure level and frequency of pure tone on elderly people’s reaction time and perceived urgency

Mengjun Wen, Hui Ma

Tianjin University, Sch Architecture, Tianjin, Peoples R China

Corresponding author's e-mail address: mahui@tju.edu.cn

ABSTRACT

The warning sounds in aging-friendly communities should be specially designed to promote safety of elderly people considering the differences in the auditory ability between elderly and young people. This study aims at revealing the effect of different sound pressure levels and frequencies of pure tone on the elderly’s reaction time and perceived urgency, and how they differ from the effect on young people. The results showed that increase of sound pressure level significantly shortened reaction time and promoted perceived urgency of the elderly. Frequency of pure tone had a significant impact on the elderly’s reaction time, while it had no significant impact on young people’s reaction time. At low sound pressure levels, the elderly’s reaction time got shorter as the frequency increased from 125 Hz to 1,000 Hz. However, the elderly stated that the highest perceived urgency was at 500 Hz, which was lower than that of young people (1,000 Hz or 2,000 Hz). The inconformity between reaction time and perceived urgency of pure tone implied that both of them should be considered in alarm design for elderly people.

INTRODUCTION

Rapid development of deep aging in China and many other countries in the past decades has become an increasing concern. In communities with a growing proportion of elderly population, the special needs of elderly people cannot be ignored. Elderly people are also one of the vulnerable groups in emergency situations, because aging affects the visual ability, hearing ability and also the ability to move. The auditory signal is an important source of information to supplement the visual cues in the case of an emergency and hearing impairment can hinder people’s capability of receiving necessary messages to flee from danger. Therefore, the unique characteristics of the elderly’s hearing ability of auditory signals should be specially considered.

The design of auditory signals/alarms has been investigated as early as 1980s when Patterson [1] first developed the guideline for the construction of auditory warnings in flight-deck and put forward the pulse-burst system of alarm in 1982. Based on this system, Patterson et al. [2] developed the alarm sounds for medical equipment in hospital in 1986. Hellier & Edworthy’s research [3] in 1989 raised the issue of urgency matching between the sound parameters and subjective urgency perception. It is now well established from a variety of studies [4-9] that many spectral and temporal acoustic parameters have effects on adults' perceived urgency of auditory signals.

Considering the differences in the hearing system between young adults and elderly people in many aspects [10], it is necessary to investigate if there are differences in urgency perception in these two groups of people and if special design in auditory signals is needed for elderly people. However, the auditory alarm signals for elderly people have received scant attention in the research literature. Butler & Oldman [11] have raised the issue of alarm systems design for the elderly and discussed the placement of the alarm loudspeaker. Wong & Leung [12] studied fire alarm audibility in elder care centers and recommended the minimum required fire alarm sound pressure level (SPL). Bruck et al. [13] investigated the elder's arousal thresholds from sleep to some smoke alarm signals. These prior researches mainly focused on the effect of SPL on the elderly's audibility of alarm signals. Spectral acoustic parameters are also important factors in the elderly's perception of alarms. It remains unclear how the interaction of spectral acoustic parameters and SPL affects the elderly's perception of alarms. This study aims to start from the basic mechanism of urgency perception of sounds, and frequency of pure tone was set as the basic spectral acoustic parameters that were examined in this study.

Most researches on urgency perception were carried out with the subjective measurement [4,5,7], in which sounds could be either evaluated individually using a rating scale, ranked in a group, or compared in pairs [14]. Also, there were some researchers who have utilized the objective measurement of reaction time (RT) to sounds to provide evidence from behavior [7,9]. It was considered that results of reaction time would supplement and extend the results of subjective measurement. To provide a comprehensive understanding of urgency perception of elderly people, both subjective evaluation on perceived urgency and objective measurement of reaction time were taken in this study.

The research questions addressed in this paper are:

1) How will the frequency and sound pressure level (SPL) affect the reaction time of elderly people? Would the results be consistent with the young people?
2) How will the frequency and SPL affect the subjective evaluation on perceived urgency of elderly people? Would the results be consistent with the young people?
3) Is the result of reaction time and perceived urgency consistent with each other? What is the mechanism underlying these two measurements?

METHODS

Participants

Before the experiment, audiometry was conducted to get the participant's hearing level, and participants with high level of hearing impairment were excluded. A total of 22 older participants (five female), whose ages ranged from 57 to 66 years (mean = 62.1 years, standard deviation, SD = 3.08 years), were recruited from the public. The cognitive ability for all elderly participants were good. There were also 16 young participants (seven female) for comparison in this experiment whose ages ranged from 18 to 25 years (mean = 23.1 years, SD = 1.96 years).

Stimuli and apparatus

The stimuli in this experiment were single frequency sounds (pure tones) of three levels of SPL (40 dB, 50 dB, and 60 dB) and six levels of frequency (125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz and 4,000 Hz). The sound samples were generated with a standardized digital sound properties (44.1 kHz sampling frequency, 32 bit depth) using Matlab R2016a software [15]. Every sound was 1s in duration, including a 0.02s onset and a 0.02s offset ramps. There was a 0.2s silence gap before the next presentation. The stimuli were presented in dB SPL.

The experimental sessions were run using the Psychophysics Toolbox extensions [16] in Matlab on a computer equipped with a Steinberg UR242 external soundcard. Stimuli were presented binaurally via a AKG K702 headphone set. In the reaction time experiment, participants responded by pressing a STRICH one-button handhold switch. The experiment was conducted in a semi-anechoic room in School of Architecture, Tianjin University.

Procedure

The process of the experiment was controlled by an experimenter with a program. This study took a standard simple reaction time procedure. Prior to reaction time data collection, a training session was given to each participant. After the training, a total of 30 stimuli were presented consecutively. All stimuli were presented in a randomized order across participants and trials. Reaction time was measured twice.

Considering the participation of elderly people in the experiment, a pre-test was conducted with 6 elderly people to select proper experimental paradigm in subjective measurement. In the pre-test, questions of the rating scale, ranking and paired comparison were asked. The participants in the pre-test agreed that the experimental task for paired comparison was the most understandable one and the easiest one to answer. Therefore, approaches taken for subjective evaluation in present study would be paired comparison on urgency.

After the first reaction time measurement, participants were asked to perform the paired comparison on the perceived urgency of two sounds presented. Participants were instructed to name the one (the first or the second) which is perceived to be more urgent after hearing both stimuli three times and give the reason. Also, a training session was given to each participant prior to data collection. This pairwise comparison took incomplete and balanced experimental design. The presentation order of the pairs as well as the order of items within each pair were randomized to control for the effect of order. Participants were allowed to take a break between groups of variables in order to prevent fatigue. The entire experimental session lasted about an hour and 15 minutes.

Ethics approval statement

This study was approved by the Ethics committee of Tianjin University. All participants gave written consent before the experiment.

RESULTS

Analysis on reaction time data

Anticipations (RTs < 0.100s) were discarded in data sorting [9,17]. For each participant, two RTs for each stimulus were averaged. RTs that were beyond two standard deviations above the mean were recognized as outliers [18] and excluded in this study. In the outlier exclusion for reaction time data, for elderly participants, 16/396 (about 1/25) of data were excluded as outliers. For young participants, 16/288 (about 1/18) were excluded.

A factorial ANOVA was performed to examine the main effects and interaction effects of the age group, SPL and frequency on the reaction time. This analysis revealed a significant main effect for the age group ($F(1, 616)=10.149$, $p< .05$) and SPL ($F(2,616)= 12.539$, $p< .001$).

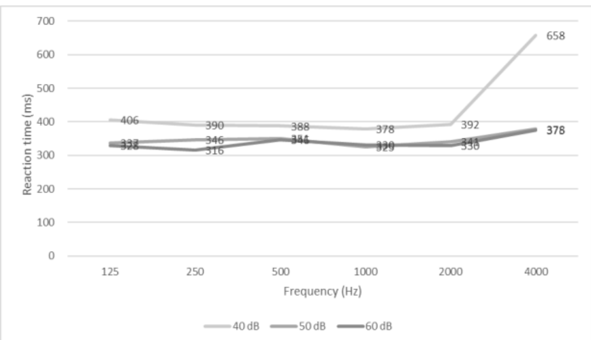
There is significant difference between the two age groups' mean reaction times. Due to the interactions between factors, the detailed analyses were carried out, and effects of SPL and frequency on the reaction time of each age group were analyzed separately. When considering the effect of different SPLs on reaction time, the reaction times of all frequencies under each level of SPL were averaged to get a mean reaction time, and the result was shown in table 1.

Table 1: the mean reaction times at each level of SPL and their difference value

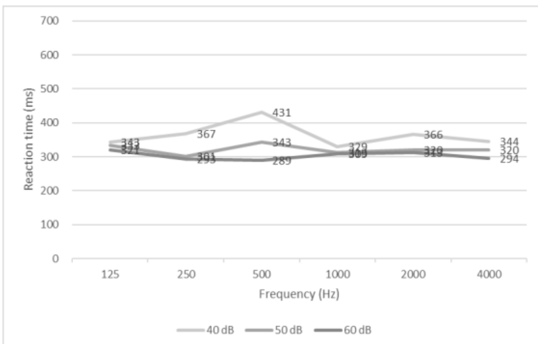
Reaction time (ms)	Elderly	Young
$RT_{40\ dB}$	435	363
$RT_{50\ dB}$	346	322
$RT_{60\ dB}$	338	303
$RT_{40\ dB}$ - $RT_{50\ dB}$	89	42
$RT_{50\ dB}$ – $RT_{60\ dB}$	9	19

For the elderly group, SPL had a significant effects ($F(2,362)=8.609$, $p<.001$) on the reaction time. The elderly group's mean reaction time got shorter with the increase of SPL. A significant difference in reaction time was found between 40 dB (M = 435 ms) and 50, 60 dB (M = 345 ms, 338 ms). For the young group, SPL also had significant effects ($F(2,254)=7.591$, $p<.01$) on the reaction time, with average reaction time at 40 dB (M = 363 ms) being significant longer than it is at 50, 60 dB (M = 322 ms; 303 ms). However, when SPL goes from 40 dB to 50 dB, the reduction of elderly group's average reaction time brought by the increase of SPL ($RT_{40\ dB}$ - $RT_{50\ dB}$) was more substantial (89 ms) when compared with the young group (42 ms), which meant that the effect of increase of SPL on elderly's reaction time is stronger than it is on young people. When SPL goes from 50 dB to 60 dB, the reduction in reaction time of both age groups was not substantial. Also, table 1 showed the gap between the mean reaction times of two age groups at each level of SPL. In order to reduce the gap, an effective way is to increase the SPL for elderly people. To get to the level of young group's mean reaction time at 50 dB (M = 322 ms), the SPL for elderly group higher than 60 dB (M = 338 ms) was needed. In other words, about 10 dB increase in SPL for elderly people is needed to reach the same level of reaction time of young people.

To analyze the effect of frequency and interaction of frequency and SPL, the elderly and young's mean reaction times at different frequencies under different SPLs are presented in Figure 1.



(a) Elderly group



(b) Young group

Figure 1: The elderly and young's average reaction times at different frequencies under different sound pressure levels

Frequency of pure tone had a significant effect on the elderly's reaction time ($F(5,362)=3.356$, $p<.01$). From figure 1 (a), at the SPL of 40 dB and 50 dB, the reaction times to the frequency of 1,000 Hz was the shortest comparing with the reaction times of other frequency level. When the SPL increased to 60 dB, the reaction times to other lower frequency domain (around 250 Hz) also got shorter, and the reaction times at 125 - 2,000 Hz were all very short. At all levels of SPL, in the frequency domain from 1,000 Hz to 4,000 Hz, the reaction times lengthened as the frequency went up, which means that the reaction sensitivity weakened with frequency getting higher. At frequency as high as 4,000 Hz, the reaction time would be significantly long. Frequency did not show a significant effect on the young group's reaction time. Also, in figure 1 (b), the curve showed no obvious trend.

The reduction of mean reaction time to sounds of each frequency with the increase of SPL in experiment was shown in table 2. For the elderly group, at high frequency domain (near 4,000 Hz), the reduction on reaction time brought by the increase of SPL would be more substantial ($((RT_{40\ dB} - RT_{50\ dB}) + (RT_{50\ dB} - RT_{60\ dB})) / 2 = 142$ ms) than it is at other frequencies. For the young group, the differences in reaction times were not significant.

Table 2: The elderly and young group's reduction in reaction times to sound of each frequency with the increase of SPL

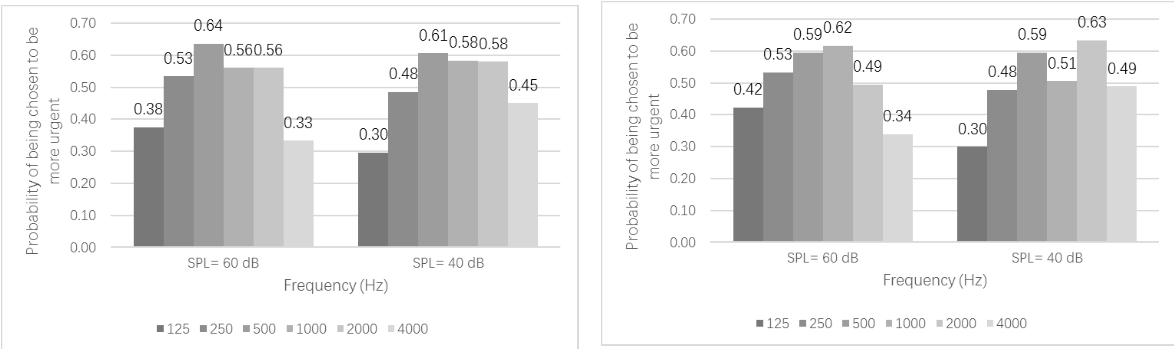
Frequency (Hz)	$((RT_{40\ dB} - RT_{50\ dB}) + (RT_{50\ dB} - RT_{60\ dB})) / 2$ (ms)	
	Elderly	Young
125	39	11
250	37	37
500	21	71
1,000	24	10
2,000	31	27
4,000	142	25

Analysis on paired comparison data

In the paired comparison data processing, comparisons of stimuli performed by every single participant were placed into a comparison matrix [19]. The group comparison matrixes were obtained by adding up the per-participant comparison matrix in an age group. Then, the vote matrix was converted into probability matrix, and the probability of being chosen to be more urgent was obtained from averaged row possibility.

Two levels of SPL were involved in the pair-comparison, which is 40 dB and 60 dB. When comparing the pure tones of the two levels of SPL, at all frequencies in experiment (125 Hz – 4,000 Hz), almost all of the sounds at louder SPL were subjectively rated by the elderly and young group to be more urgent, which is consistent with the common sense that the louder the sound, the more urgent it is.

For the elderly and young group, the results obtained from perceived urgency comparison of different frequency under different SPL was presented in figure 2.



(a) Elderly group (b) Young group

Figure 2: The elderly and young's subjective evaluation on sounds at different frequencies under different sound pressure levels

Compared with the young group (most urgent at 1,000 Hz under 60 dB, 2,000 Hz under 40 dB), the elderly group tended to evaluate lower frequency domain (around 500 Hz) to be more urgent. As shown in figure 2 (a), for the elderly group, the change in SPL didn't bring much change in the ranking of perceived urgency of sounds. At the two levels of SPL, in the frequency domain of 125 Hz – 500 Hz, the probability of being chosen to be more urgent increased with the frequency, and peaked at 500 Hz. The subjective perceived urgency evaluation on 1,000 Hz and 2,000 Hz were almost consistent. To summarize, when comparing with other frequencies, the frequency domain near 500 Hz was more likely to be perceived to be more urgent, and it was followed by frequency near 1,000Hz and 2,000 Hz.

As shown in figure 2 (b), for young group, in the frequency domain of 125 Hz - 500 Hz, perception on urgency degree increased as the frequency went up, and in the frequency domain of 2,000 Hz - 4,000 Hz, urgency degree declined with frequency. There were differences in the ranking of the urgency evaluation of two SPLs: at 60 dB, the 1,000 Hz sounded more urgent than other sounds; But at 40 dB, the urgency evaluation on the 1,000 Hz showed an obvious decline, with the reasons of 'this tone whispered all the time', 'heard everyday', and 'don't have much alertness'. This was an unexpected outcome.

Interestingly, for both elderly and young group, when the SPL dropped from 60 dB to 40 dB, the possibility for 125 Hz to be chosen to be more urgent got lower, while the possibility for 4,000 Hz got higher. It meant when sound is too faint to hear, the possibility of evaluating the sound of frequency as high as 4,000 Hz to be more urgent is higher than the sound of frequency near 125 Hz.

The comparison between objective and subjective measurements

In this study, two measurements were taken to measure the effect of auditory signals on elderly and young people: objective reaction time and subjective paired comparison. When comparing these two measurements, it is considered that if the reaction time is shorter, the sensitivity of reaction is stronger, and that is consistent with the subjective evaluation of being more urgent.

When considering the main effect of SPL, there is a consistent monotonic trend in the results of objective and subjective measurements: for two age groups, the increase of SPL will lead to increased sensitivity of reaction, and also can bring higher awareness of urgency.

When considering the effect of different frequencies and the interaction of frequency and SPL, the elderly group's ranking of measurement results of different frequencies under SPL of 60 dB and 40 dB is presented in table 3. The young group's reaction times are very short and the differences between frequencies are not significant, so the ranking of it would not be compared with the subjective evaluation.

Table 3: The elderly group's ranking of the objective and subjective measurement of the pure tone of different frequency under SPL of 60 dB and 40 dB

SPL	Reaction time	Subjective evaluation
SPL = 60 dB	250 Hz< 125 Hz< 1,000 Hz< 2,000 Hz < 500 Hz< 4,000 Hz	500 Hz > 1,000 Hz = 2,000 Hz > 250 Hz > 125 Hz > 4,000 Hz
SPL = 40 dB	1,000 Hz<500 Hz< 250 Hz< 2,000 Hz< 125 Hz < 4,000 Hz	500 Hz > 1,000 Hz > 2,000 Hz > 250 Hz > 4,000 Hz > 125 Hz

As can be seen from table 3, when considering the effect of frequency, the results of objective and subjective measurements did not change with the increase of frequency monotonically. There was inconsistency between the objective and subjective measurements: the shortest reaction time and evaluation of most urgent sound lied in different frequency domain. For the elderly people, when the SPL is at low level (40 dB), the shortest reaction time is at 1,000 Hz. At high SPL (60 dB), reaction times at other frequencies were also as short as 1,000 Hz. However, the subjective evaluation displayed little difference between high and low SPL, with the highest evaluation at 500 Hz, and then at 1,000 Hz and 2,000 Hz. The differences in the ranking revealed that for the elderly people, the effect of interaction of frequency and SPL is stronger on the reaction time than it is on the subjective evaluation. Reaction times to some frequencies changed a lot when the SPL changes, while the subjective evaluation of different frequencies tended to keep stable no matter how loud the sound is. Also, in table 3, some consistency existed in the ranking of objective and subjective measurements. At the SPL of 40 dB, longer reaction time and lower urgency evaluation were observed for frequency near 125 Hz and 4,000 Hz.

Comparing the results of reaction time and subjective evaluation, both consistency and inconsistency were observed, and inconsistencies in the result were mainly affected by interaction of frequency and SPL.

DISCUSSION

Together the results of two measurements provided important insights into the perception process of pure tone. It is argued that both measurements show one perspective of the urgency perception process. The measurement of reaction time reveals the intuitions and instincts, which take effects at the initial stage of the urgency perception. In contrast, the subjective evaluation is based on experiences, which takes effects at the stage of urgency judgement after the initial stage. It is the mechanisms in different processing stages underlying the two measurements that caused the difference in the results. As revealed by Guillaume et al.'s work [20], both low-level psychoacoustic processes and higher level cognitive processes contribute to people's reaction to sounds. Both initial and subsequent processing stages play important roles in the urgency perception process, so the selection of proper auditory alarm signals may be based on the results of these two measurements.

CONCLUSION

This study investigated the effect of pure tone's SPL and frequency on elderly's perception. Two measurements were taken in the experiment, which were reaction time and subjective urgency evaluation. The most obvious finding to emerge from the analysis is that the change of these two acoustic parameters can bring large promotion in the reaction time reduction and urgency evaluation of alarming sounds. An effective way to significantly reduce the reaction time of the elderly at all frequencies is to increase the SPL. At low SPLs, the elderly's reaction time got shorter as the frequency increased from 125 Hz to 1,000 Hz, and the reaction time to the frequency of 1,000 Hz was the shortest comparing with the reaction time of other frequency level. However, the elderly stated that the highest perceived urgency was at 500 Hz, which was lower than that of young group (1,000 Hz or 2,000 Hz).

The results of the two measurements were compared and the mechanisms underlying the difference of two measurements were also discussed. The inconsistency might root from the different processing stages in perception. Though pure tone is not recommended to be alarm signals, the results could be the basis of further research. For effects of more spectral acoustic parameters on the perception of elderly people, further researches are on the way.

Acknowledgements

This work was supported by the National Natural Science Foundation of China [grant numbers. 51978454]. The authors gratefully acknowledge the kind support of the all participants. We would also like to show our gratitude to Jiaxing Zhu and Feng Niu for helping with the making of sound material.

REFERENCES

[1] Patterson, R. D. (1982). Guidelines for auditory warning systems on civil aircraft. Civil Aviation Authority.

[2] Patterson, R. D., Edworthy, J., & Lower, M. C. (1986). Alarm sounds for medical equipment in intensive care areas and operating theatres. University of Southampton, Institute of Sound and Vibration Research.

[3] Hellier, E., & Edworthy, J. (1989). Quantifying the perceived urgency of auditory warnings. Canadian Acoustics, 17(4), 3-11.

[4] Edworthy, J., Loxley, S., & Dennis, I. (1991). Improving auditory warning design: Relationship between warning sound parameters and perceived urgency. Human factors, 33(2), 205-231.

[5] Momtahan, K. L. (1990). Mapping of psychoacoustic parameters to the perceived urgency of auditory warning signals (Doctoral dissertation, Carleton University).

[6] Hellier, E. J., Edworthy, J., & Dennis, I. A. N. (1993). Improving auditory warning design: Quantifying and predicting the effects of different warning parameters on perceived urgency. Human factors, 35(4), 693-706.

[7] Haas, E. C., & Casali, J. G. (1995). Perceived urgency of and response time to multi-tone and frequency-modulated warning signals in broadband noise. Ergonomics, 38(11), 2313-2326.

[8] Burt, J. L., Bartolome, D. S., Burdette, D. W., & Comstock Jr, J. R. (1995). A psychophysiological evaluation of the perceived urgency of auditory warning signals. Ergonomics, 38(11), 2327-2340.

[9] Suied, C., Susini, P., & McAdams, S. (2008). Evaluating warning sound urgency with reaction times. Journal of experimental psychology: applied, 14(3), 201.

[10] Gordon-Salant, S., Frisina, R. D., Fay, R. R., & Popper, A. (Eds.). (2010). The aging auditory system (Vol. 34). Springer Science & Business Media.

[11] Neville, Y. B. (1981). Alan Butler and Christine Oldman (eds.), Alarm Systems for the Elderly:(Report of a Workshop held at the University of Leeds, September 1980), Department of Social Policy and Administration, University of Leeds. Ageing & Society, 1(3), 456-456.

[12] Wong, L. T., & Leung, L. K. (2005). Minimum fire alarm sound pressure level for elder care centres. Building and Environment, 40(1), 125-133.

[13] Bruck, D., Thomas, I., & Kritikos, A. (2006). Investigation of auditory arousal with different alarm signals in sleeping older adults (Doctoral dissertation, Fire Protection Research Foundation).

[14] Perez-Ortiz, M., & Mantiuk, R. K. (2017). A practical guide and software for analysing pairwise comparison experiments. arXiv preprint arXiv:1712.03686.

[15] Borgo, M., Soranzo, A., & Grassi, M. (2012). MATLAB for Psychologists. Springer Science & Business Media.

[16] Kleiner, M., Brainard, D., & Pelli, D. (2007). What's new in Psychtoolbox-3?.

[17] Luce, R. D. (1986). Response times: Their role in inferring elementary mental organization (No. 8). Oxford University Press on Demand.

[18] Lachaud, C. M., & Renaud, O. (2011). A tutorial for analyzing human reaction times: How to filter data, manage missing values, and choose a statistical model. Applied Psycholinguistics, 32(2), 389-416.

[19] Tsukida, K., & Gupta, M. R. (2011). How to analyze paired comparison data. WASHINGTON UNIV SEATTLE DEPT OF ELECTRICAL ENGINEERING.

[20] Guillaume, A., Pellieux, L., Chastres, V., & Drake, C. (2003). Judging the urgency of nonvocal auditory warning signals: Perceptual and cognitive processes. Journal of experimental psychology: Applied, 9(3), 196.