Finger Response Times to Visual, Auditory and Tactile Modality Stimuli

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***Abstract*—The purpose of this paper was to investigate finger response time to visual, auditory and tactile modality stimuli in the context of man-machine-interface. A total 94 right-handed Chinese participants (11 to 60 years old) took part in the visual, auditory, and tactile stimuli tests. In the visual and auditory stimuli tests, once the visual or auditory mode of a number was shown, the participants pressed the corresponding number on the keypad with their right or left middle finger as soon as possible. In the tactile stimuli test, the stimuli were produced through a vibrator that was worn on the participants' right wrist or right leg near ankle. Once the participants detected a vibration, they pressed the number key '8' with their right middle finger as quickly as possible. The result showed that the time in response to the tactile stimuli was significantly shorter, followed by the auditory stimuli and then the visual stimuli. The response time of tactile stimuli was 28% and 34% shorter than that of auditory and visual stimuli, and the response time of auditory was 5% shorter than that of visual stimuli. The location of tactile vibrator i.e. wrist and leg did not have any significant influence on response time. Factors like age, gender, education level, time spent on computer, left/right finger, and choice alternative, however, had significant effects on the response time of an individual to visual and auditory stimuli. The response time decreased with an increase of age up to the 21-30 years, and thereafter it increased gradually with an increase of age. Females were found to respond faster than males. The response of tertiary and secondary education groups was faster than that of primary education group. Besides, the longer the time spent on computer in daily life, the shorter was the response time. In addition, the right finger response time was shorter than the left finger response time. The response on single-choice task was the fastest, followed by two-choice task and then four- and eight-choice tasks. The findings of this study provide a useful reference for engineers and designers to realize how the different modality channels could interfere the operators, so as to design a more user-friendly human-machine-interface.**

***Index Terms*—response time, visual stimulus, auditory stimulus, tactile stimulus, human-machine-interface**

I. Introduction

Human response time can be partitioned into reaction time and movement time [1]. Reaction time refers to the duration from onset of a signal calling for a response until the beginning of the response, while movement time denotes the duration from the beginning of the response to its completion. Reaction time tasks can be distinguished according to the number of diverse stimuli in a task that need to be responded with a specific motor reaction. In case the number of stimuli is equal to one, this kind of reaction time task is called simple reaction time task; if higher than one, it is defined as choice reaction time task. The simple reaction time task is an issue when only one particular stimulus can occur and the same response is always required, whereas there can be several different stimuli in the choice reaction time task that requires a particular response for each stimulus.

There are a number of studies addressed to the topic of response time. Research studies have been conducted to analyze the influence of different factors on human response time such as stimulus modality, stimulus intensity, foreperiod, gender, stimulus-response alternatives, and stimulus location [2-4]. The human-machine-interfaces nowadays not only routinely utilize the visual and auditory stimuli modality, but also increase the use of tactile modality. These modality input/output channels can be found in the design of driving vehicle systems, military communication system, smoke detector alarm, lighting control system, and many other industrial applications for provision of timely alert information [5-9].

One of the common examples of visual modality stimuli is flashing, which has long been used as a signal coding method in the marine, aviation, and road transport industries, and shown to be able to attract attention from a distance [10]. A red flashing light is an international aviation industry signal for 'do not land' [11]. To enhance road safety for pedestrians, a crosswalk warning system with flashing lights adjacent to a marked crossing is used [12].

In addition to the use of vision, auditory modality is widely used in transport, health care, and industrial environments as it has an immediate arousing effect [13]. Arrabito et al. [14] investigated the conveyed level of urgency of non-verbal auditory alarms used in helicopter environments, and found that the 'siren-like quality sounds' were judged as the most urgent. The siren type of auditory alarm was also rated more hazardous than the buzzer one [15].

Besides, tactile modality has also been found more useful to improve the reaction time of operators in an unmanned aerial vehicle ground control station simulation [5]. The use of in-car tactile navigation display could also result in better driver performance and reduce their workload [16].

In this paper, we investigated finger response time to the visual, auditory and tactile modality stimuli. The study was also planned to analyze the influence of age, gender,

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education level, time spent on computer, left/right finger, choice alternative, and tactile location on response time. The findings would provide a useful reference for engineers and designers to integrate visual, auditory or tactile signal into human-machine systems more effectively and efficiently.

II. METHOD

A. Participants

A total of 94 right-handed Chinese participants (43 males and 51 females), aged between 11 and 60 years, voluntarily took part in this study. All of them were in good visual, auditory, and physical condition at the time of the study.

B. Apparatus and Stimuli

An application program prepared with Visual Basic 6.0 and a notebook computer (ASUS Eee PC 4G) were used to generate visual, auditory, and tactile stimuli and to capture the participants' responses. The visual stimuli were dark digit numbers on a grey background presented at the centre of the 7" computer screen with 800 x 600 resolution. The auditory stimuli were speech signals of numbers (in English) emitted from the built-in speaker. The tactile stimuli were produced through a vibrator (Fig. 1) that was worn on the participants' right wrist or right leg near ankle positions. The intensities of the stimuli were set at levels that were able to produce sufficient alerting effect for requesting responses from the participants. A USB number pad was placed at a convenient location at the front of the participants and was used to enter the corresponding response number (Fig. 2). An adjustable chair was provided for the participants to perform the study.

Fig. 1. The vibrator used in this study (left photo). The vibrator was worn on a participant' right leg (right photo).

C. Procedure

The participants were asked about their age, gender, education, average time spent on computer per day, and dominant hand. Then the participants were briefed with the objectives and procedure of the study. Sixty-nine of the participants (32 males and 37 females) were involved in the visual and auditory stimuli tests, and the remaining 25 participants (11 males and 14 females) were in the tactile stimuli test. For each test, the participants were seated in front of the computer at a viewing distance of approximately 60 cm.

C.1. Visual Stimuli Test

The visual stimuli test consisted of a simple reaction time task, and two-, four-, and eight-choice reaction time task. Each task was ended until 10 correct responses were made. The details of the simple and choice reaction time tasks are as follows.

(i) Simple reaction time task: For each trial, a number '8' was presented at the centre of the computer screen. The participants responded by pressing the corresponding number i.e. 8 on the keypad with their middle finger as fast as possible.

(ii) Choice reaction time tasks: For each trial, the possible stimulus was either number '2' or '8' in the two-choice reaction time task; number '2', '4', '6', or '8' was shown in the four-choice reaction time task; and number '1' '2', '3', '4', '6', '7', '8', or '9' was given in the eight-choice reaction time task. Once the number appeared at the centre of the computer screen, the participants were required to press the corresponding number key with their middle finger as soon as possible.

At the beginning of each reaction time task, the participants were told which number set would appear (i.e. possible stimuli) for them to get familiar with the response modes. The possible stimuli were sufficiently well learned. Both left and right middle fingers were tested. The sequence of testing of reaction time tasks and left/right fingers was counterbalanced across participants to minimize order effects.

The number key '5' served as a resting position in each trial for the simple and choice reaction time tasks. The participants pressed the number key '5' to initiate a trial and placed their middle finger on the number key '5' to wait for stimulus presentation. A stimulus would appear between 150 to 300 ms randomly after the number key '5' was pressed and last until a response was captured by the computer.

C.2. Auditory Stimuli Test

Instead of the stimuli were presented in the auditory mode, the procedure of the auditory stimuli test was exactly the same as that of the visual stimuli test.

C.3. Tactile Stimuli Test

The tactile stimuli test was conducted in the mode of a simple reaction time task. The tactile stimuli were produced by a vibrator worn on the participants' right wrist or right leg near ankle positions. The test was ended after 10 correct responses were made for each tactile position. The number key '5' gave a resting position in each trial. Once the participants detected a vibration, they pressed the number key '8' with their right middle finger as quickly as possible.

7	8	9
4	5	6
1	2	3

Fig. 2. The layout of keypad used in this experiment. The number key '5' was acted as a resting position in each trial of the tests.

III. RESULTS

A total of 5520 responses (69 participants x 4 reaction time tasks x 10 trials x 2 test fingers) were recorded in either the visual stimuli test or auditory stimuli test. A total of 500 responses (25 participants x 10 trials x 2 tactile positions) were collected in the tactile stimuli test. Descriptive statistics of response time to visual, auditory, and tactile stimuli was assessed. Appropriate statistical analysis was performed to study whether age, gender, education level, time spent on computer, left/right finger, choice alternatives, and sensory modality had significant effects on response time. Post hoc

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analysis with Holm's sequential Bonferroni method was then carried out if necessary. Significant level was set at 0.05.

IV. Response time to visual stimuli

Table I shows response time to visual stimuli in terms of six factors: age, gender, education level, time spent on computer, left/right finger, and choice alternatives.

A. Age

ANOVA showed that age had significant effect on left/right finger response time for each choice task (ANOVA, p's < 0.05). Post hoc analysis with Bonferroni method showed how age groups differed significantly from each other in terms of left/right finger response time.

Regarding the left finger response time, for *all choice tasks* the response time of 51-60 years was significantly longer than that of 11-20 years, 21-30 years, and 31-40 years. In the *single-choice task*, the response time of 31-40 years was significantly shorter than that of 41-50 years. In the *two-choice task*, the response time of 41-50 years was significantly shorter than 51-60 years. In the *four-choice task*, the response time of 41-50 years was significantly shorter than 51-60 years but significantly longer than 21-30 years and 31-40 years.

Regarding the right finger response time, for *all choice tasks*, the response time of 51-60 years was significantly slower than that of 11-20 years, 21-30 years, and 31-40 years. In the *single-choice task*, the response of 41-50 years was also significantly slower than that of 21-30 years. In the *two-choice task*, the response of 21-30 years was significantly faster than that of 11-20 years and 31-40 years, while the response of 41-50 years was significantly slower than that of 11-20 years, 21-30 years, and 31-40 years. In the *four-choice task*, the response time of 41-50 years was significantly faster than that of 51-60 years but slower than 21-30 years. In the *eight-choice tasks*, the response time of 51-60 years was significantly slower than that of 41-50 years.

B. Gender

There was significant difference between males and females in left/right finger response time. For the left finger response time, the response time of females was significantly shorter than that of males in single choice task ($t = -0.290$, $df = 688$, $p < 0.05$). No significant differences were found between females and males in two-, four- and eight-choice tasks.

For the right finger response time, the response time of female was significantly shorter than that of males in eight-choice task ($t = -2.393$, $df = 686$, $p < 0.05$). There were no significant differences between females and males in single, two- and four-choice tasks.

C. Education Level

Education level had significant effect on right/left finger response time for each choice task (ANOVA, p's < 0.05). Bonferroni post test was then conducted to determine which education levels differed significantly from each other.

For the left finger response time, tertiary education group had significantly shortest response times, followed by secondary education group and then primary education group in the single, two- and four-choice tasks. Under the eight-choice task, both secondary and tertiary education group responded significantly faster than primary education group, but no significant difference was found between secondary and tertiary education groups.

For the right finger response time, in the four-choice task, tertiary education group responded significantly faster than both primary and secondary education groups, while the response time of secondary education group was significantly shorter than primary education group. In the single, two- and eight-choice tasks, both secondary and tertiary education groups responded significantly faster than primary education group ($p < 0.05$), but no significant difference was revealed between secondary and tertiary education groups.

D. Time Spent on Computer

Time spent on computer had significant effect on right/left finger response time for each choice task (ANOVA, p's < 0.05). Bonferroni post test showed that, in general, the longer the time spent on computer in daily life, the shorter was the left/right finger response time. However, for the left finger response time, there were no significant differences between 'less than 2 hours' and '2 to 4 hours' groups in the single choice task, between '2 to 4 hours' and '4 to 6 hours' groups in the four-choice task, and. between '4 to 6 hours' and 'more than 6 hours' groups in the single, two- and four-choice tasks. For the right finger response time, there were no significant differences between '4 to 6 hours' and 'more than 6 hours' groups in the single, two-, four- and eight-choice tasks, and between '2 to 4 hours', '4 to 6 hours' and 'more than 6 hours' groups in the single choice task.

E. Left/Right Finger

The left finger response time was significantly longer than the right finger response time across all choice tasks (Independent samples t test, p's < 0.05).

F. Choice Alternative

Choice alternative had significant effect on right/left finger response time (ANOVA, p's < 0.05). The right/left finger response time of the single-choice task was significantly shorter, followed by two-choice task and then four- and eight-choice tasks.

V. Response time to auditory stimuli

Table II shows response time to auditory stimuli in terms of six factors: age, gender, education level, time spent on computer, left/right finger, and choice alternatives.

A. Age

Age had significant effect on right/left finger response time across all choice tasks (ANOVA, p's < 0.05). Bonferroni post test was then conducted to determine which age groups differed significantly from each other.

For the left finger response time**,** the response of 51-60 years was significantly slower than that of 11-20 years, 21-30 years, and 31-40 years across all choice tasks. The response of 51-60 years was also significantly slower than that of 41-50 years in the single-, four-, and eight-choice tasks. In the *single choice task*, the response time of 41-50 years was significantly longer than that of 21-30 years and 31-40 years, and the response time of 11-20 years was significantly longer than that of 21-30 years and 31-40 years. In the *two- and four-choice task*, the response time of 21-30 years was also

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significantly shorter than 11-20 years, 31-40 years, and 41-50 years.

For the right finger response time, the response of 51-60 years was significantly slower than that of 11-20 years, 21-30 years, 31-40 years, and 41-50 years across *all choice tasks*. In the *single, two- and four-choice tasks*, the response time of 21-30 years was significantly shorter than that of 41-50 years. As compared to the response time of 31-40 years, the response time of 21-30 years was significantly shorter in the two- and four-choice tasks but was marginally significantly longer in the eight-choice task.

B. Gender

Males responded significantly slower than females in two- and four-choice tasks with left/right finger (Independence samples t test, p's < 0.05). No significant differences were found between males and females in single and eight-choice tasks.

C. Education Level

Education level had significant effect on left and right finger response time across all choice tasks (ANOVA, p's < 0.05). Bonferroni post test showed that the higher the education level, the shorter was the left/right finger response time in single, two- and four-choice tasks. In eight-choice task, the left/right finger response time of primary education group was significantly longer than that of secondary and tertiary education groups, whereas no significant difference was found between secondary and tertiary education groups.

D. Time Spent on Computer

Time spent on computer had significant effect on left/right finger response time across all choice tasks (ANOVA, p's < 0.05). In general, as the time spent on computer increased, the left/ right finger response times decreased accordingly. However, Bonferroni post test indicated that regarding the left finger response time, no significant difference was found between '4 to 6 hours' and 'more than 6 hours' across all choice tasks. In the single-choice task, no significant difference between 'less than 2 hours' and '2 to 4 hours' was also found. In the four-choice task, there was also no significant difference between '2 to 4 hours' and '4 to 6 hours'. In the eight-choice task, no significant differences were also revealed between '2 to 4 hours' and '4 to 6 hours', and between '2 to 4 hours' and 'more than 6 hours'.

Regarding the right finger response time, in the single-choice task, there were no significant differences between '2 to 4 hours' and '4 to 6 hours', and between '4 to 6 hours' and 'more than 6 hours' groups. In the two-choice task, no significant differences were found between '2 to 4 hours' and 'more than 6 hours', and between '4 to 6 hours' and 'more than 6 hours'. In the four-choice task, no significant difference was also found between '4 to 6 hours' and 'more than 6 hours'. In the eight-choice task, no significant differences were revealed between '2 to 4 hours' and '4 to 6 hours' groups, between '2 to 4 hours' and 'more than 6 hours' groups, and between '4 to 6 hours' and 'more than 6 hours' groups.

E. Left/Right Finger

The left finger response time was significantly longer than the right finger response time across all choice tasks (Independent samples t test, p's < 0.05).

F. Choice Alternative

Choice alternative had significant effect on right/left finger response time (ANOVA, p's < 0.05). The right/left finger response time of the single-choice task was significantly shorter, followed by two-choice task and then four- and eight-choice tasks.

VI. Response Time to Tactile Stimuli

The average response time for tactile stimuli was 0.385ms with standard deviation of 0.071ms. The position of vibrator did not have any significant influence on tactile response time (Independent samples t test, t = =1.401, df = 498, p > 0.05).

The average response time for visual stimuli across all choice tasks and response fingers was 0.517ms with standard deviation of 0.181ms. With regards to auditory stimuli, the average response time across all choice tasks and response fingers was 0.493ms with standard deviation of 0.178ms. Kruskal-Wallis test was conducted and showed that type of stimulus had significant effect on response time (χ^2 = 304.9, df = 2, p < 0.05). Time in response to visual stimuli was found to be significantly longer than that to auditory stimuli (U = 1.4E + 07, p < 0.05) and tactile stimuli (U = 741737.5, p < 0.05). Time in response to auditory stimuli was also significantly longer than that to tactile stimuli (U = 8725215, p < 0.05).

VII. Discussion

A. Summary of Findings

This study was about finger response time in response to the visual, auditory and tactile stimuli for right-handed people. Time in response to the tactile stimuli was significantly shorter, followed by the auditory stimuli and then the visual stimuli. The response time for visual stimuli was 5% and 34% longer than that for auditory and tactile stimuli, respectively. The response time for auditory stimuli was 28% longer than that for tactile stimuli.

In response to the visual and auditory stimuli, age, gender, education level, time spent on computer, choice alternative, and preferred/non-preferred finger were found to have significant effects on response time. The response time decreased with an increase of age up to the 21-30 years. After that, the response time increased gradually with increase of age. Females were found to respond faster than males. The response time of tertiary and secondary education groups was also faster than that of primary education group. Besides, the longer the time spent on computer in daily life, the shorter was the response time in this study. The right finger response time was shorter than the left finger response time. In addition, the response on single-choice task was the fastest, followed by two-choice task and then four- and eight-choice tasks.

In response to the tactile stimuli, the tactile location i.e. wrist and leg did not have any significant influence on response time.

B. Interpretation and Implications of the Findings

The factors of age, gender, education level, left/right finger, time spent on computer, choice alternatives, and

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stimulus modality were associated with response time significantly in this study. These results were supported by the findings of a number of previous studies of similar nature.

With regard to the age, in general, the response time decreased with increase of age up to 21-30 years, and thereafter the response time increased with increase of age. Similar results have been reported by Ashoke et al. [17] with a group of subjects of 5 to 70 years of age. They found that the response was faster with an increase of age up to 21-25 years and then the response gradually slower with increase of age.

For the gender factor, females responded faster than males. This finding was similar to the research done by Han et al. [18], which revealed that females responded faster than males during the detection of threat cues in visual scenes.

Regarding the education level, the response time of tertiary and secondary education groups was shorter than that of primary education group. Previous studies indicated that the differences in reaction time tasks were due to processing time [19], and higher levels of education were associated with greater central executive efficiency and information processing speed [20-21]. This implies that the higher the education level, the quicker will be the response. The study here proved this earlier hypothesis.

The right finger was shown to respond faster than the left finger of right-handed people in this study. Peters and Ivanoff [22] also found that right-handed people responded faster with their right-hand when using a right-handed computer mouse. The results of these studies might be due to extensive right hand practice on keypad and mouse entries in the context of computer usage. This can be proved by our findings that time spent on computer in daily life were positively associated with response time here. In addition, the preferred hand muscle strengths are generally stronger than non-preferred ones [23], and a correlation was found to exist between muscle strength and reaction time [24]. The differences in left and right finger response time might also result from the muscle strength differences between the hands.

Regarding the effect of choice alternative, the response on single-choice task was the fastest, followed by two-choice task and then four- and eight-choice tasks. Previous studies (e.g. Kamitani et al. [25]) also found that the response on choice reaction time task was significantly longer than simple reaction time task. According to this study, the possible explanation of such finding was that choice reaction task required not only stimulus perception and execution of the response but also decision-making processes.

With respect to the sensory modality, time in response to the tactile stimuli was significantly shorter, followed by the auditory stimuli and then the visual stimuli. This finding was similar to the studies done by Huang et al. [9], which also showed that sound and haptic alarm signals induced shorter braking response than visual ones. Brebner and Welford [26] indicated that the variation of response across sensory modalities might be due to differences in the peripheral mechanisms such as some sensory systems are more sensitive than others. The temporal sensitivity of the skin is found to be very high which is close to that of the auditory system and larger than that of the visual system [27]. Since the tactile and auditory stimuli are more sensitive than visual stimuli, the tactile and auditory response time here are faster than the visual response time.

Overall, the factors of age, gender, education level, left/right finger, time spent on computer, choice alternatives, and stimulus modality were significantly related to response time. This implies that these factors should be taken into account when designing new human-machine-interfaces with the use of visual, auditory or tactile modality stimuli in future. This study would be a useful reference for engineers and designers to realize how the different sensory outputs could interfere the operators. The nature of stimulus modalities here was considered individually. There is an increasing multi-sensory alert system with visual, auditory, and tactile integration. The combination of stimulus modalities effects should be considered in future study.

VIII. Conclusion

This study was about finger response time to the visual, auditory and tactile stimuli for right-handed people. Time in response to the tactile stimuli was the shortest, followed by the auditory stimuli and then the visual stimuli. The possible differential effects of age, gender, education level, time spent on computer, left/right finger, choice alternative, and location of tactile vibrator on response time were also determined. The findings of this study provided engineers and designers useful information on how the different modality channels could interfere the operators, so as to design a more user-friendly human-machine-interface in future.

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TABLE I
MEAN RESPONSE TIME TO VISUAL STIMULI

Factors	Level	n	Mean response time (ms)							
			Simple		Two-choice		Four-choice		Eight-choice	
			Left	Right	Left	Right	Left	Right	Left	Right
Age	11-20	50	0.39	0.37	0.47	0.44	0.59	0.57	0.66	0.64
	21-30	460	0.38	0.34	0.44	0.40	0.55	0.51	0.72	0.65
	31-40	120	0.35	0.36	0.45	0.44	0.57	0.55	0.69	0.65
	41-50	20	0.43	0.43	0.51	0.56	0.67	0.65	0.80	0.78
	51-60	40	0.47	0.45	0.65	0.62	0.81	0.79	0.94	0.99
Gender	Male	370	0.39	0.36	0.46	0.43	0.58	0.54	0.74	0.69
	Female	320	0.37	0.35	0.46	0.42	0.57	0.53	0.71	0.66
Education level	Primary	40	0.45	0.42	0.61	0.58	0.74	0.74	0.87	0.90
	Secondary	150	0.40	0.36	0.48	0.43	0.59	0.56	0.73	0.68
	Tertiary	500	0.37	0.35	0.44	0.41	0.55	0.51	0.71	0.65
Time spent on computer	< 2 hours	40	0.45	0.44	0.60	0.62	0.76	0.77	0.91	0.94
	2-4 hours	150	0.41	0.37	0.48	0.44	0.59	0.56	0.73	0.68
	4-6 hours	190	0.36	0.35	0.44	0.40	0.55	0.51	0.70	0.64
	> 6 hours	310	0.37	0.34	0.44	0.41	0.55	0.51	0.72	0.65
Overall	-	690	0.38	0.36	0.46	0.43	0.57	0.54	0.73	0.67

n – number of responses collected

TABLE II
MEAN RESPONSE TIME TO AUDITORY STIMULI

Factors	Level	n	Mean response time (ms)							
			Simple		Two-choice		Four-choice		Eight-choice	
			Left	Right	Left	Right	Left	Right	Left	Right
Age	11-20	50	0.39	0.36	0.48	0.47	0.55	0.51	0.69	0.64
	21-30	460	0.35	0.32	0.41	0.38	0.50	0.47	0.70	0.65
	31-40	120	0.33	0.33	0.49	0.45	0.55	0.51	0.67	0.59
	41-50	20	0.43	0.40	0.53	0.50	0.61	0.57	0.75	0.67
	51-60	40	0.51	0.49	0.58	0.63	0.77	0.75	0.93	0.88
Gender	Male	370	0.36	0.33	0.45	0.43	0.54	0.51	0.71	0.66
	Female	320	0.35	0.34	0.43	0.41	0.52	0.48	0.71	0.64
Education level	Primary	40	0.49	0.45	0.58	0.59	0.71	0.68	0.86	0.82
	Secondary	150	0.38	0.35	0.45	0.44	0.56	0.52	0.72	0.65
	Tertiary	500	0.34	0.32	0.42	0.39	0.51	0.48	0.69	0.64
Time spent on computer	< 2 hours	40	0.50	0.47	0.58	0.61	0.73	0.71	0.89	0.81
	2-4 hours	150	0.38	0.36	0.45	0.44	0.55	0.52	0.72	0.67
	4-6 hours	190	0.34	0.32	0.42	0.39	0.51	0.47	0.68	0.63
	> 6 hours	310	0.34	0.32	0.43	0.40	0.51	0.48	0.69	0.64
Overall	-	690	0.36	0.34	0.44	0.42	0.53	0.50	0.71	0.65

n – number of responses collected

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