

**DRIVER ONSET BRAKING TIME: THE UNCERTAINTY
INVOLVED WITH APPROACHING AN INTERSECTION**

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SUMMARY

Many automobile accidents occur at intersections, which are often controlled by stop signs and traffic lights. Understanding how a driver interprets, anticipates, and responds to stop signs and traffic lights could help increase the safety and usability of these devices. How drivers brake when approaching traffic control devices of differing levels of uncertainty was examined and compared. The uncertainty associated with the variable message presented in a traffic light was compared to a stop sign. A series of videos depicting these scenarios were shown to drivers, and their brake onset times were recorded. It was discovered that drivers began braking sooner when approaching a stop sign compared to approaching a traffic light. Several other interactions were also investigated, but found to be of no significance.

CHAPTER 1: INTRODUCTION

According to the National Highway Traffic Safety Administration, intersections are among the most dangerous locations on US roads. For example, 8,797 fatalities occurred at intersections in 2006 (NHTSA, 2006) and in the US, nearly 700,000 collisions occur annually at stop signs alone (Retting, Weinstein, & Solomon, 2003). The story reads the same for stop lights, and in one year, drivers running red lights caused some 260,000 crashes (Retting, Ulmer, & Williams, 1999). There is clearly something amiss here. The uncertainty involved with traffic control devices such as the stop signs and traffic lights that are ubiquitous at intersections could hold a share of the responsibility. Could the uncertainty associated with an unexpected signal play a role in how or where drivers brake when approaching an intersection?

Drivers are taught the meaning of stop signs and traffic lights before they even begin to drive. Children's games, toys and the media incorporate red as stop, and green as go, and the world famous octagon shaped, red sign, which means stop. Colorblind individuals aside, few people have difficulty recognizing red as stop and green as go. Drivers know exactly how to interpret the simple meaning of these markers. It has even been noted that there is an overwhelming agreement among drivers as to exactly what shade of red is appropriate for a stop sign (Sivak, Flannagan, Gellatly, & Luoma, 1992).

If the knowledge and meaning of these devices is clear, then what could be causing the problem of drivers failing to stop, or stopping inappropriately? Datta,

Schattler, and Datta (2000) cite high approach speeds and an aggressive driving style as the primary cause of failure to stop at a red light. McKelvie (1987) cites a decreasing trend in driver compliance at stop signs, noting that the percentage of drivers that made complete stops at several intersections in Canada decreased steadily over a six-year period between 1979 and 1985. In related follow-up research several years later, Trinkaus (1993) found a similar decreasing trend in full stops, with an increase in no-stops and rolling-stops, and suggests a change in driver interpretation of the stop sign. This research, however, aims to investigate how drivers brake when they do intend to stop.

The point when the brake pedal is applied is pivotal in determining whether a driver will stop in time when approaching an intersection or approaching another object in the roadway. There has been a wealth of research conducted on the physical time that it takes a driver to place his/her foot on the brake. Green (2000) estimates that a driver can detect a signal and move the foot from the accelerator pedal to the brake pedal in about 0.7 to 0.75 seconds. Warshawsky-Livne and Shinar (2002) conducted a similar but more encompassing reaction time experiment that involved event uncertainty (expected events vs. unexpected events), transmission type (automatic vs. manual transmission), gender (male vs. female), and age (novice vs. experienced drivers). Their results show increasing reaction times for increased age, and uncertainty and a gender difference. There has also been a wealth of research conducted on cancer patients (Yuen, et al. 2007), Parkinson's patients (Singh, Pentland, Hunter, & Provan, 2007), and older drivers (Zhang, et al. 2007) to study their respective

braking reaction times, and how these conditions have detrimental effects on reaction time. These types of research, experiments, and studies tend to focus on situations that cause a reduction of braking ability, increased braking reaction time, or, a delayed brake onset time. This research is uninterested in these aspects, and will instead examine healthy, experienced drivers, focusing more on event uncertainty than other causes of decreased brake onset time.

In research done by Kelling (2006), a time until collision/contact/catch, or *tau* (τ) was discovered in drivers approaching a tangible object in the roadway, such as another vehicle. *Tau* is a direct measurement of the driver onset braking point in a variety of approach situations. His research examined how drivers brake to avoid rear end collisions, and how drivers perceive other approaching vehicles. His results show different reaction times for different rates of closure, dependent on the driver's speed, or on the speed of the approaching vehicle. He argues that the act of mental processing accounts for almost all of the variation in braking reaction times. If this is indeed the case, objects with more variability or uncertainty will have a larger impact on brake reaction time because of increased mental processing demands. This result is consistent with his finding that brake onset time occurs sooner for a stationary vehicle in the roadway, compared to a moving vehicle, which is somewhat counter-intuitive. Approaching a moving vehicle requires more interpretation from the driver, as the driver now has to judge not only his own speed, but also the speed of the approaching vehicle. This scenario involves more uncertainty than approaching a stationary vehicle. This is even more problematic, as he also argues that drivers are not very proficient at

calculating their own speed or their rate of closure, even with a stationary object. This research gives some insight to the time required to make sense of an uncertain situation, and react to it appropriately.

The research conducted by Green (2000) and by Warshawsky-Livne and Shinar (2002) highlights the particularly pertinent aspect of braking time as related to situational or event uncertainty. Green (2000) notes that the most important factor relating to reaction time is driver expectation. He found that expectation could increase reaction time by as much as a factor of two. At the speeds involved with driving, this can have an enormous impact on stopping time. He notes that when a driver is fully aware of when and where a brake event will occur, the brake reaction time is about half that of a surprise braking event. Warshawsky-Livne and Shinar (2002) also found that event uncertainty has a substantial impact on reaction time. This event uncertainty came in the form of varying degrees of knowledge of when and where a brake stimulus would occur. The time it took a driver to physically move his/her foot from the accelerator to the brake was not affected by this uncertainty. However, the increased reaction time involved in processing the information was more than enough to significantly increase the driver's overall braking time. The mental processing of a braking event, especially those involving increased degrees of uncertainty, is detrimental to the whole process of braking. It seems that when a driver is uncertain about what is present in the roadway ahead, or encounters an unexpected stimulus, it takes a longer time to interpret and react. However, when

it is clear to a driver that he/she must brake, the whole process can be carried out in less time.

Drivers frequently encounter changing or unpredictable stimuli while driving. While a stop sign always means stop, a traffic light's message can be interpreted in a number of ways, from stop (red), to proceed (green), or the even more variable and vague case of stop only if it is safe to do so (yellow). There is little uncertainty involved for a driver when approaching a stop sign, except in the case when the stop sign is obscured. Typically, the message contained in a stop sign is unchanging, clear and does not physically move, or create situational uncertainty. A driver approaching a traffic light, on the other hand, has a variety of uncertain events that may occur. If the light is red, it could change to green, or if it is currently green, it may soon change to yellow, then red. The first important step for the driver is identifying the current state of the light. Many driver education programs encourage their students to look for other hints, cues, and signs of the light's status. Drivers can read signals like pedestrian crossing signs, or look for other vehicles waiting at the intersection, to assist in identifying if the light is "stale", or if it has recently changed. If the light has been in its current state for a while, the driver must understand that there is a good chance it will soon change. This extra knowledge could help to reduce the uncertainty, but will not completely remove it. Before the change from green to red occurs, or even from red to green, there is still a great amount of uncertainty involved. The driver must ask if the light will change, or if it will stay in its current state. If the status of the light does change, a decision must be made quickly to assess the ability to

stop, or to continue through the intersection. This uncertainty creates an increased reaction time, and may explain some of the problems involved when drivers approach intersections.

Because of the variable nature of the situations involved here, it is imperative to treat each individual scenario separately, and braking is rarely exactly the same from one case to another. However, attempting to understand each individual scenario involves variables that are very complex in nature. Brake onset time will always differ between varieties of scenarios. Visibility and luminance levels play a key role, as does weather and even the type of vehicle, among many other variables. These questions will not be addressed here, as they add many layers of complexity, and do not appear to be very generalizable. The key aspect of this research will center on uncertainty, and avoid other possibly detrimental variables.

In research conducted by Ryan (2007), drivers were found to exhibit braking behaviors that are consistent with these other findings. Drivers began to brake earlier when approaching a stop sign or another vehicle than when approaching a traffic light. The driver's brake onset time occurred sooner when approaching a stop sign, and was delayed when the driver was approaching a red light. It was assumed that the uncertainty involved with traffic lights led to the later onset braking time when drivers approached the intersection.

1.1 Statement of Purpose

We are left with a couple of questions pertaining to how drivers brake when approaching an intersection. Answering these questions will ultimately

assist the design of traffic control devices and vehicles to more safely and effectively handle this common scenario. The first question deals with how drivers brake when approaching a stop sign compared to how they brake when approaching a traffic light. This question aims to compare a low uncertainty situation with a higher uncertainty condition. The second question deals with how drivers brake when approaching a traffic light with varying levels of uncertainty of the light's status. This question aims to compare different levels of higher uncertainty conditions. These two questions lead to two hypotheses. It is hypothesized that: (1) drivers will begin braking earlier when approaching a stop sign than when approaching a traffic light because of the increased uncertainty associated with a stop light, and (2) when a driver is uncertain about when a light will change from green to red, his/her brake onset time will be delayed compared to his/her brake onset time in the case of an expected light change.

CHAPTER 2: METHOD

2.1 Participants

Twenty-nine participants were recruited for the experiment. One participant's data was removed from the analysis because of a technical issue and two participants' data were removed for failure to follow instructions. Thus, data from 26 participants were analyzed. The subject pool consisted of Georgia Tech students currently taking a psychology class and recruited through Experimentrix and their psychology classes. No demographic information was collected on the participants, as this information was not deemed pertinent to the research. All the participants were at least 18 years of age, and all had been licensed drivers for at least three years. This was verified by asking participants to present a valid driver's license. All participants were treated according to Institutional Review Board procedures.

2.2 Design

Participants were randomly assigned to one of three groups that differed in levels of uncertainty. The levels of uncertainty were defined by the number of locations where the car's distance from the intersection would trigger a traffic light change. For one group of participants ($N=7$), the stop light changed from green to red when the car reached one specific location, 1534 ms before reaching the intersection. This was termed the low uncertainty level condition. For another group of participants ($N=11$), the light changed at one of three different locations, 1034 ms, 1534 ms, or 2334 ms before reaching the intersection. This

was termed the medium uncertainty level condition. For the final group of participants (N=8) the light changed at one of five different locations, 1034 ms, 1234 ms, 1534 ms, 1967 ms, or 2334 ms before reaching the intersection. This was termed the high uncertainty level condition. Drivers in each condition also reacted to approaching stop signs. In order to minimize predictability of when the light or stop sign would appear, each of the videos had three different starting points.

Those in the low uncertainty level condition reacted to 90 stop sign videos, and 90 traffic light videos. Those in the medium uncertainty level condition reacted to 45 stop sign videos, and 135 traffic light videos, broken down into 45 videos for each of the three light change points. Those in the high uncertainty level condition reacted to 30 stop sign videos, and 150 traffic light videos, broken down into 30 videos for each of the five light change points. Each participant viewed and reacted to 180 videos.

The dependent variable was brake onset time. Brake onset time was measured as the moment that the driver put his/her foot on a brake pedal. Brake reaction time for each trial was calculated as the time between the light change and brake onset. Based on this value, *tau* was calculated as the time between brake onset and time to reach the intersection.

2.3 Materials

The experiment was run on a computer with at least a 17-inch LCD display. A scale model toy slot car was used for developing the videos. The slot car was a typical 1:32 scale car that traveled around an oval track. The speed of the scale

model car was calibrated to represent a vehicle traveling at approximately 40 mph. A wireless camera was attached to the top of the slot car. As the car traveled around the track the video feed from the camera was broadcast to a TV tuner card in the computer. The computer recorded the videos, which were then edited for three different starting positions. The end result was a total of 18 different videos (five different stopping points for the traffic light and one stop sign crossed with the three starting points).

The experimental program was created and executed using Inquisit 2.0 desktop software (Millisecond, 2005). The participants sat at a computer interfaced with a brake pedal at their feet. In addition to using the computer to present the video the computer recorded the brake onset time. The brake pedal apparatus was similar to the brake pedal used for a computer driver or racing game (see Figure 1). The participants were tested in a group setting of up to three at a time.

2.4 Procedure

First, the participant's driver's license was checked, they then read and signed a consent form and the experiment was described. The participants were told in advance which experimental condition they were assigned to. Each participant sat down at a computer workstation, was shown the brake pedal apparatus and how it works, and was then told to start the experiment by pressing the space bar on the keyboard. The experiment lasted for approximately 45 minutes and consisted of participants watching and reacting to a series of short videos displayed on the computer screen.

The videos depicted a driver's perspective view of a well-lit road ahead, with nothing present on the side of the road, and no other vehicles or distracters present. The participant was told to depress the brake pedal at the point where they would typically begin braking if driving a real vehicle in an every day driving event.

The participants watched and reacted to two general types of videos; approaching a stop sign and approaching a traffic light that always changed from green to red (no yellow light included). The time the participant's foot pressed the brake pedal was recorded. This time was used to calculate how far from the light or sign the driver began braking (*tau*) and how long after the light changed the driver began to brake (reaction time).

CHAPTER 3: RESULTS

The first hypothesis, that drivers will begin braking earlier when approaching a stop sign, than when approaching a traffic light, was found to occur. A 3 (uncertainty level) x 2 (intersection type) repeated measures analysis of variance revealed that drivers began braking earlier when approaching a stop sign than when approaching a traffic light, $F(1,23) = 14.83$, $p = .0008$. There were no significant differences among the three levels of uncertainty nor was there a significant interaction between the levels of uncertainty and the intersection type. Separate analyses were performed on each of the three different groups and their brake reaction time for the stop sign and the traffic light. A significant difference between the traffic light condition and approaching a stop sign in the high uncertainty level condition was observed, $F(1,6) = 13.857$, $p = .01$. The low uncertainty level condition and the medium uncertainty level condition showed no significant difference between stop signs and traffic lights. See Table 1 for the F values associated with the repeated measures analysis of variance for the high and low uncertainty level calculations and the t value for the low uncertainty level calculation. See Table 2 for a list of the mean brake onset times for the three uncertainty conditions at the two intersection types.

The second hypothesis, that when a driver is uncertain about when a light will change from green to red, his/her brake onset time will be delayed compared to an expected light change, showed an appropriate trend, but not at a significant level ($p > 0.05$). Thus, this null hypothesis cannot be refuted. A means comparison was used to compare the differences in *tau* across the uncertainty

conditions at each intersection type. Particular attention was paid to the number three light change point, and to the stop sign, as all the participants experienced these. Table 3 shows the mean *tau* values for each light change point. For the number three light change point participants in the high uncertainty level condition began braking an average of 820 ms before the intersection, and 706 ms after the light changed. Participants in the medium uncertainty level condition began braking an average of 1109 ms before entering the intersection, and 441 ms after the light changed. Participants in the low uncertainty level condition began braking an average of 972 ms before entering the intersection, and 592 ms after the light changed. For the stop sign condition, participants in the high uncertainty level condition began braking an average of 1177 ms before entering the intersection. Participants in the medium uncertainty level condition began braking an average of 1473 ms before entering the intersection. Participants in the low uncertainty level condition began braking an average of 1364 ms before entering the intersection. See Figure 2 for a graph of this data.

CHAPTER 4: DISCUSSION

The results support the first hypothesis, showing a significant difference in brake onset times between stop signs and traffic lights. This result has important consequences in the context of uncertainty in driving, and the difference in how drivers behave when approaching traffic control devices. The message contained in a red light and a stop sign should be the same, so there are other factors at play. The inherent uncertainty associated with traffic lights could account for some of this difference. However, more research is clearly needed on this aspect, and perhaps this finding can provide some justification for doing so. Would it be better if every intersection had a stop sign, as opposed to a traffic light? That is not likely a good solution, but these results indicate that something should be changed in the design of traffic lights if they are difficult for drivers to respond to.

The results do not show overwhelming evidence for the second hypothesis. No significant results were found between drivers' uncertainty levels. However, trends in the data can be seen to bolster the argument for uncertainty playing a role in driver braking behavior. The trend of onset braking time could lead to more elaborate investigation of this idea. Perhaps greater levels of driver uncertainty would yield some more significant findings.

It appears as if statistical power plays a key role in the lack of significance in the data. The power of the calculations was observed to be low for almost every calculation. The uneven number of participants in each of the uncertainty conditions detracts from the statistical power. Also, the lack of a large number of participants also limits the statistical power of the calculations. Perhaps a repeat

of this experiment, with more data points, and a more even spread of the conditions would yield more significant results. By including more drivers, and allowing the uncertainty conditions to have equal N's, this experiment could yield different results.

The uncertainty involved with approaching a traffic light plays a key role in interpreting the results. Drivers did begin braking earlier when approaching objects that did not vary, and that involved little interpretation or uncertainty. When a driver expects a light to change to red, the brake onset time tends to occur sooner than it does when the driver cannot anticipate when the light will change. As more variability, or uncertainty, is introduced into the scenario, the onset braking time tends to decrease. The driver's brake onset time also consistently occurred sooner when approaching a stop sign than when the driver approached a traffic light under any of the expectation conditions. This decrease in onset braking time could lead to dangerous situations where a driver fails to stop in time to avoid a collision.

An interesting result shows a change in the brake onset time for the stop sign across variability conditions. The stop sign condition was the same no matter what uncertainty condition level the participant was assigned to. Even though that is the case, drivers consistently stopped later when approaching the stop sign when in the high uncertainty condition. This result could be visualized as meaning that the number of traffic lights that you encounter on your way to work in the morning affects how you stop at stop signs. This result shows that a driver's uncertainty level could be affected by recent past experiences with

uncertainty. In other words, as more uncertainty is introduced to the driver, even certain situations begin to seem more uncertain. More investigation into this phenomenon will be required.

An unexpected result shows that the medium uncertainty level condition yielded earlier brake onset times than the low uncertainty level condition, though not at a significant level. Because the low uncertainty level condition contains only two common data points, (the stop sign condition, and the number three traffic light condition), it is hard to extrapolate the results to the other points. Participant boredom may have contributed to this finding also. After watching 45 min of the same two videos, the participant may have become tired of the task, affecting his/her brake onset point. Perhaps controlling for this aspect could lead to different results.

Some shortcomings of this research involve the realism of the videos. They were recorded in 1:32 scale, and this may detract from the ability to easily generalize these results. Because they were shown on a simple computer monitor also detracts from the realism aspect. The lack of visual cues in the video to aid the driver in determining how fast he/she is traveling may also have a detrimental effect on onset braking time in a way that is not often the case for the driver of a real vehicle. Much care was taken to ensure the uniformity of the speed, visual angle, and overall effect of the videos across the different situations: however, there is always the possibility that differences between the videos led to differences in braking time. Perhaps limiting the uncertainty to only three conditions was not enough. The ideal high uncertainty condition would be a light

that changed from green to red on a random sequence. Including a condition involving a traffic light that stays green could also increase the uncertainty. All the participants were young college students, which may not be indicative of the population as a whole. There were no detrimental consequences for late braking in this simulation, or not following directions in this experiment. While driving in a real vehicle on a roadway, the consequences of late braking, or failure to stop at an intersection, range from legal action, to varying levels of life and property loss from a collision. These serious consequences may adjust driver perception and behavior beyond a simple simulation. Another shortcoming of the research is the lack of the yellow light included in the simulations. The lack of the yellow light takes away some of the realism of the videos. It also makes the results difficult to apply outside of the simulations. When the yellow light is included, uncertainty should increase, which may make some of the low uncertainty level conditions more on par with the medium or even high uncertainty level conditions.

Future research in this area could help further define and broaden our understanding of how drivers brake at intersections. More research is needed to address how the yellow light plays a role in increasing the uncertainty involved. These results justify methods dealing with decreasing the yellow light uncertainty, but more research is needed to investigate this scenario. Other factors, such as how other vehicles present at the intersection may also need to be explored. If there is a vehicle already waiting at the intersection, does that decrease uncertainty?

The implications of this research could help people to design more efficient and driver friendly intersections, and vehicles. The safety level of intersections could also improve if more is known about how and when drivers begin to brake. These results could also be helpful in accident reconstruction, or determining what went wrong at accident scenes. Many pedestrian crosswalks have recently added the feature of a countdown timer, to indicate how long the pedestrian has to cross the intersection. Redesigning the traffic light to include a visible count-down-timer that informs the driver of exactly when the light will change could help to reduce uncertainty. With the proliferation of GPS units in cars, it wouldn't be a stretch to use these devices to warn a driver about an upcoming unexpected intersection, or eminent red light change. This data will also be useful in making better adaptive cruise control systems that are safer and that react more naturally. Accident avoidance systems in cars could also benefit from knowing when and how drivers brake when approaching intersections. Can we imagine a system that lets a driver know exactly when and where the next red light or stop sign will occur, completely eliminating the uncertainty involved with approaching an intersection?

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Figure 1



Figure 1 shows the brake pedal apparatus used in the experiment.

Figure 2

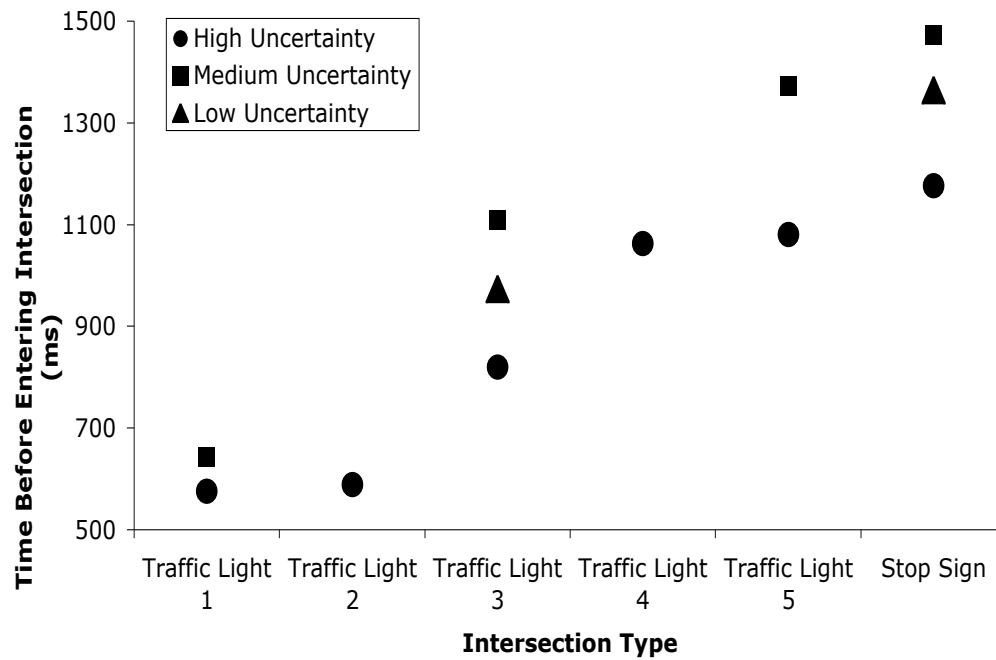


Figure 2 shows the data points associated with the five light change positions, and stop sign, over the three uncertainty conditions. Notice the relationship between high, medium, and low uncertainty conditions at the number three traffic light change, and at the stop sign.

Table 1

Repeated measures ANOVA interaction: stop sign * traffic light	df	Mean Square	F	Sig.
Across Uncertainty Levels	1	1713048.18	14.83	0.0008**
High Uncertainty	1	372281.990	13.857	0.010**
Medium Uncertainty	1	175013.116	4.776	0.057

Paired samples t-test: intersection3 * stop sign	df	Mean	t	Sig.
Low Uncertainty	6	-390.479	-2.364	0.056

Table 1 shows the F and t values for the calculations of mean differences in *tau* for traffic light verses stop sign conditions across uncertainty level. The high and medium conditions were calculated with a repeated measures ANOVA, while the low uncertainty condition was calculated with a t-test.

Table 2

	Uncertainty Condition		
	Low	Medium	High
Traffic Light	973.23857	1112.14637	815.25750
Stop Sign	1363.71715	1471.40363	1174.20000

Table 2 shows the cell means (in ms) for the three uncertainty conditions at the two intersection types. The cell means represent *tau*, or brake onset time before reaching the intersection.

Table 3

Uncertainty Condition	Light Change 1	Light Change 2	Light Change 3	Light Change 4	Light Change 5	Stop Sign
Low	-	-	972.26 ms	-	-	1363.54 ms
Medium	643.30 ms	-	1109.55 ms	-	1372.31 ms	1472.95 ms
High	576.34 ms	588.84 ms	820.46 ms	1062.89 ms	1080.61 ms	1176.74 ms

Table 3 shows the mean *tau* values for the three uncertainty conditions at each of the five light change points experienced, and at the stop sign.