ADAPTATION TO SPEED LIMIT CHANGES

Prepared for the NZAA Research Foundation

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Abstract

New Zealand (NZ), as with other jurisdictions, has recently begun reducing the speed limits on its roads to fit with safe speeds. But drivers judge the speed to drive on familiar roads with very little conscious deliberation or effort. The research contained in this report set about to examine the process of speed adaptation following the introduction of lower speed limits on many roads. The present research sought to compare speed distributions before and after speed limit changes, identify the time course of speed adaptation, identify the proportion of road users who do not adapt, and identify any road characteristics leading to good adaptation. In the first study, speed data were sampled from Waka Kotahi across thirty locations in New Zealand. Of the sites sampled twenty-one had mean speeds that exceeded the speed limit by the end of the study, but only nine sites would be considered a failure. The second stage of the study used fifty-five drivers recruited to drive a video-based simulator and answer some questions about their experience. Fully 61.22% of the participants said that it took them between one and five times on the road to adapt to the new speed limit for high speed roads, and 78.57% said this about low speed roads. Participants agreed that the roads were safer once their speed limits were lowered. Significant numbers of participants chose to drive the simulator faster than the speed limit, however, for both the high speed roads and the low speed roads. The results are discussed in terms of the predictability of roads, and the number of people who said they would drive the speed limit. The findings suggest that the look and feel of a road seems to dictate their choice of speed, unless a speed limit sign is present. The presence of a speed sign is still a powerful deterrent, and guide to memory.

Key words: adaptation, compliance, speed limit,

1. Background

After 80 years of driver behaviour research, speed choice and speed management remain among the most challenging problems in road transport. From a system perspective, speed management has significant consequences for both safety and efficiency. The Power Model suggests that high speeds increase both the severity and frequency of crashes (Elvik, 2013; Nilsson, 2004), and speed heterogeneity both increases the risk of crashes and decreases the efficiency or throughput of the road network (Garber & Ehrhart, 2000; van Nes, Brandenburg, & Twisk, 2010).

New Zealand (NZ), as with other jurisdictions, has recently begun reducing the speed limits on its roads to fit with safe speeds. In NZ, the speed limit regime is a set of regulations that dictate the maximum speeds at which vehicles are allowed to travel on different types of roads. New Zealand's speed limits are controlled by the government, speed limits are set or changed in accordance with the requirements of the Land Transport Rule: Setting of Speed Limits 2022. Waka Kotahi, the New Zealand Transport Agency (NZTA), is responsible for ensuring that process is followed by Road Controlling Authorities for local roads and for setting speed limits on the state highway network. It's important to note that these speed limits are maximums, not the recommended or safe speeds to drive, and it's recommended to adjust the speed according to the road conditions, traffic and visibility. The setting of speed limits is guided by the NZTA's Speed Management Guide (2022), which provides detailed guidance on how to conduct speed limit reviews, assessments, and the setting of new speed limits. The process involves several steps and is guided by several key principles, including road safety, traffic flow, and community consultation.

The One Network Road Classification (ONRC) is a framework used in NZ to classify and categorize the country's road network. The ONRC framework is used by Waka Kotahi NZTA

to help determine appropriate speeds for different types of roads. More recently, the One Network Framework (NZTA, 2022) seeks to classify NZ roads according to their function and the number of vehicle movements (see Figure 1). The resulting 12 road types are intended to classify elements of the transport network and assign safe speeds according to their place function while ensuring that performance of the network remains robust. In other words, it's a planning tool intended to assist in setting safe speeds.

Figure 1.1. The One Network Framework (adapted from NZTA, 2022).

The intention is to work towards predominant speed limits across the network of 60km/h, 80km/h or 100km/h. The goal is to use 20km/h increments for speed limits between 60km/h and 100km/h so that there are fewer and more recognisable speed limit categories for people to understand and recall. Over time, this will result in a greater distinction between different speed limits and better alignment with the One Network Framework, making it easier for road users to recognise the speed for the road they are travelling on.

The One Network Framework street category is one of many inputs that helps to determine the safe and appropriate speed range for a road or street. That safe and appropriate speed range then becomes one of the baseline factors for identifying a safe and appropriate speed limit. Using these resources, speed limits on all major roads in New Zealand are set. The reduction in speed limits may not, by themselves, always have the desired effect. Speed heterogeneity and overtaking without clear visibility ahead have mitigated the safety of the new speed limits. There are issues with the processes as well. Speed limits are primarily based on engineering principles and data analysis, which may not take into account the nuances of human behaviour, such as the tendency for drivers to ignore posted speed limits or drive faster than the posted limits. Habit is a powerful anchor for speed choice, choosing one's speed for a bit of familiar road is often a matter of driving the same speed one has always driven, regardless of speed limit signs or the risk of receiving an infringement notice.

Speed limit signs often go unnoticed by drivers, either because they are driving on "auto pilot" in a familiar environment or because their attention is focussed elsewhere (Charlton & Starkey, 2013; Harms & Brookhuis, 2016). Research shows that entrenched behaviour patterns produced by familiarity with a given road or road type has the effect of reducing the amount of attention spent noticing signs and increasing proceduralised driving (Harms, Burdett, & Charlton, 2021). Further, even if noticed by drivers they may not produce the desired effect because they (the drivers) may not agree with the change. They have driven the road, or very similar roads, at its previous speed for a number of years without a crash. They do not understand or appreciate the concepts of exposure or collective risk.

While acknowledging that drivers do make conscious choices that are influenced by weather conditions and surrounding traffic, there is increasing recognition that the general look and feel of a road and roadside environment has significant effects on road users' attention, the routes they choose, and the speeds they choose to drive. Importantly, these effects of the

general road environment appear to emerge with extended practice and work at an implicit level, without drivers' conscious awareness, presumably with the development of schemata for familiar roads and familiar environments.

For example, when speed limits are lowered for a particular area, drivers may initially comply with the new speed limit, but over time, they may adapt their behaviour to the previous speed limit. This phenomenon is called "speed limit anchoring," and it occurs because drivers often rely on past experiences and habits when deciding how fast to drive. Drivers judge the speed to drive on familiar roads with very little conscious deliberation or effort (Charlton & Starkey, 2013). When drivers become very familiar with specific roads or road types they can experience a time gap in their awareness of the drive and a realisation that they have not been attending to driving for some time. In fact, explicit tests of drivers' memory have shown that typical objects and actions are not noticed or are recalled with less accuracy than atypical objects and actions (Charlton & Leov, 2021). The results also showed that false memories were most common for typical objects, such as speed signs. When a sign is absent from the road environment, drivers' fill in the missing information from other cues available (Charlton & Starkey, 2017). Things such as good visibility, painted medians, and wide roads with extensive road markings may signal a high speed road while conspicuous footpaths and the proximity of residential housing appear to be cues for lower speeds. When these cues are in conflict, or are not clear, the driver may begin to search the environment for a speed sign.

The research contained in this report set about to examine the process of speed adaptation following the introduction of reductions in speed limits. Specifically, the present research sought to compare speed distributions before and after speed limit changes, identify the time course of speed adaptation, identify the proportion of road users who do not adapt, and identify any road characteristics leading to good adaptation. The research tried to obtain

speed survey data from Waka Kotahi-NZTA to find the speed distributions before and after speed limit reductions (which proved problematic). Then a comparison of the speed distributions before and after the speed limit reductions would enable us to identify the proportion of road users who do not adapt.

Following that, a simulation experiment was conducted to ascertain the individual reactions of drivers to reduced speed limits and ask them about the process of speed adaptation. The goal was to test 40-50 participants in a simulator which displayed actual footage of roads, familiar and unfamiliar, measure their speeds, and ask a series of questions about the roads, and other roads that the participants had experience with. The questions were intended to capture the individual experiences of drivers' reactions to speed limit changes, how long it took to adapt to the new limits and what they did in response. The questionnaire also asked them about the appropriateness of the new limits and their attitudes to speed limit changes generally. It was hoped that these reactions would enable us to identify road characteristics that either facilitated good speed limit adaptation or hindered it.

2. Study 1

One approach to studying the impact of speed limit changes on driver behaviour is to identify roads where speed limit reductions have been implemented and to analyse the resulting speeds. To conduct such an analysis, we selected geographical locations for which corridor data were available from Waka Kotahi, the New Zealand Transport Agency. These locations were chosen to represent a range of speed limit changes, including roads that had recently undergone speed limit reductions.

2.1. Data availability and data collection

During the data gathering stage, it became apparent that data from the state highway system and regional roads were not going to be as easy to collect as originally thought. In September of 2021 we were told that data from regional road safety engineers did not exist or were not available. After repeated enquiries we found that a source of data were available through TomTom (the consumer electronics company that gathers traffic flow data from millions of anonymous mobile phone users) for a select number of locations. Unfortunately, these data were not releasable to the public due to contractual reasons. Eventually (March 2022), a solution was found that enabled data to be downloaded and used for the present study. The resulting data set contained 30 locations and each of them were sampled four times as follows:

- one week prior to speed limit change,
- one week after speed limit change,
- three weeks after speed limit change,
- seven weeks after speed limit change.

Weekly speed data were calculated in both directions where possible, and from distinct speed limits along the corridor (some of the corridors were quite long and featured multiple speed

limit changes). Finally, speed data distributions were calculated, before and after the speed limit reductions, in an attempt to identify the proportion of road users who do not adapt.

2.2. Results

Speeds for all the corridors for which weekly data could be calculated are shown in the table below and the figures that follow.

Table 1. Locations and dates for the speed monitoring.

Location		Start date	End date
SH3 Whanganui	North Island	11 December 2020	16 March 2021
SH16 Waimauku	North Island	31 August 2020	4 December 2020
SH5 Waiotapu	North Island	29 June 2020	2 October 2020
SH1 Puhoi	North Island	7 June 2021	10 September 2021
SH60 Tākaka	South Island	28 April 2021	1 August 2021
SH1 Templeton	South Island	24 February 2021	30 May 2021
SH35 Te Puhia Springs	North Island	2 July 2021	5 October 2021
SH22 Drury	North Island	23 June 2020	29 September 2020

2.2.1. SH3 Whanganui

First is SH3 from Westmere to Whanganui, a section of road with 21 crashes between 2009 to 2018, in the top 10% of the regional network that would benefit from speed management. Beginning at Virginia Road, the 50 km/h speed limit moved out to Tirimoana Place and the road became 80 km/h through to Blueskin Road (approximately). From Blueskin Road north the road became 100 km/h. The change in speed limits occurred on 18 December 2020 and speeds were calculated over a three-month period after the speed limit reduction was implemented.

Figure 2.1. shows the speeds for SH3 and that compliance was generally good throughout this corridor. The solid bars show the mean speeds and the whiskers on their top show the C85 speeds, the speeds that only 15% of drivers exceeded. Prior to the speed limit change, drivers were observed to be traveling at an average speed of approximately 83-90 km/h, with C85

speeds ranging from 94-101 km/h. However, after the speed limit reduction, average speeds decreased to approximately 77 to 83 km/h, C85 speeds dropped to 84-95 km/h. Speeds stabilised at that new, lower speed throughout the remainder of the monitoring period with final speeds three months after introduction of the new limit of 80 km/h, C85 speeds were 88 km/h.

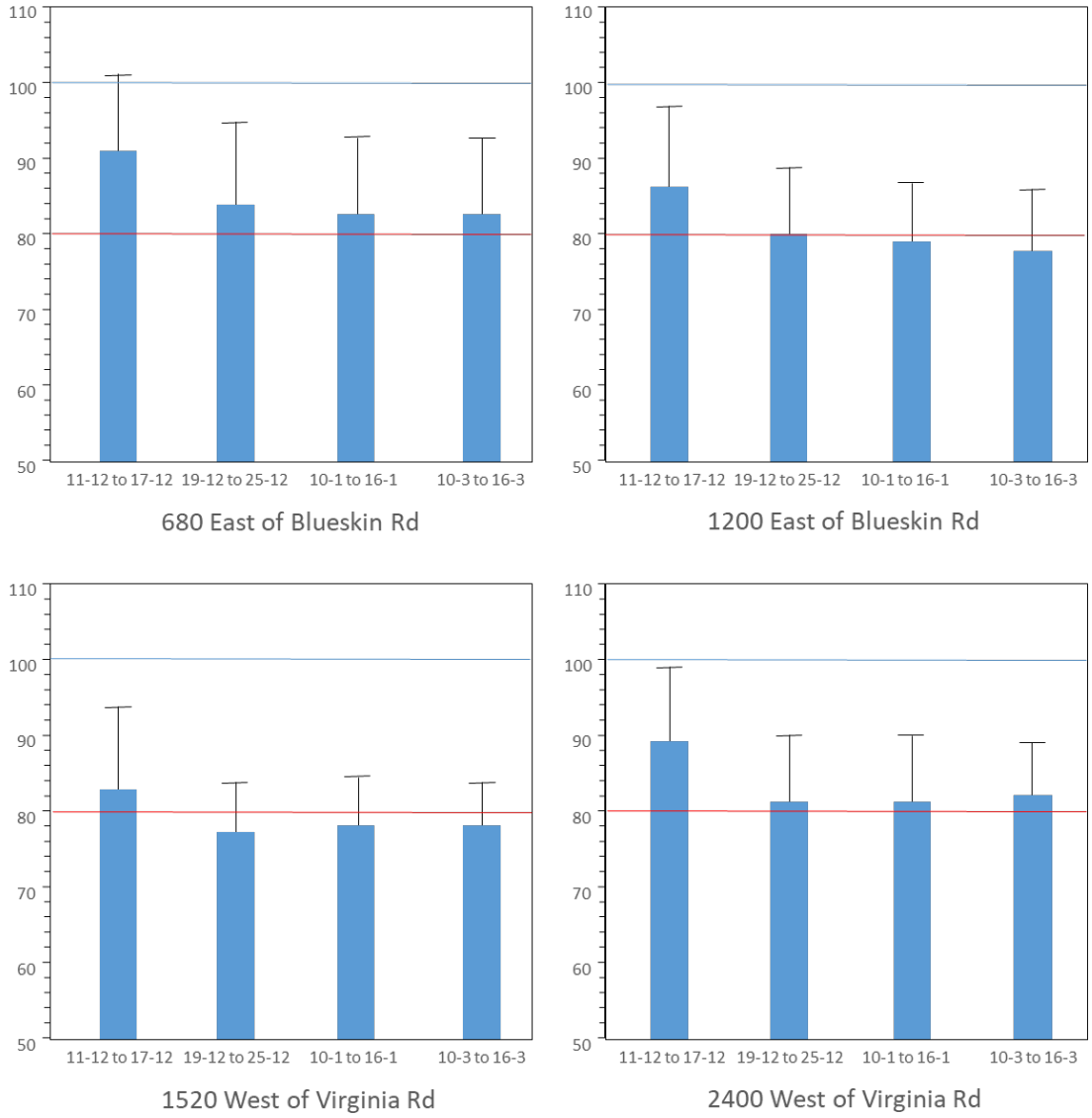
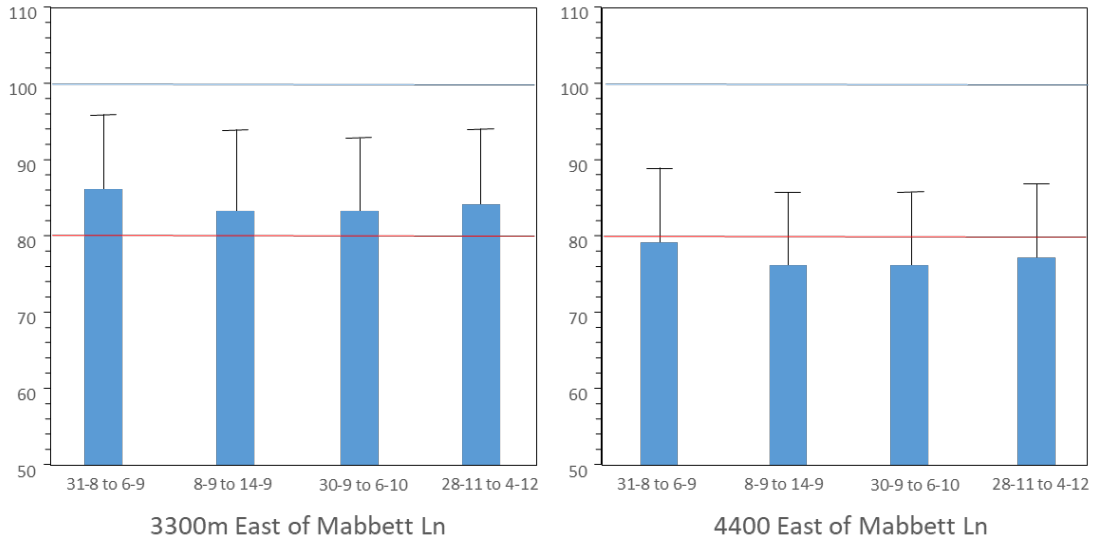


Figure 2.1. SH3 Eastbound (top panels) and SH3 Westbound (lower panels). Bars indicate C50 speeds at each date, and whiskers indicate C85. The first column of each graph show the free speeds prior to any speed limit change, subsequent bars show speeds after the change.

2.2.2. SH16 Waimuku

SH16 is part of the Twin Coast Discovery Highway and the section of road that had its speed reduced is just East of Waimuku. This section of 80 km/h road comes from a 60 km/h road (formerly 70 km/h) from Waimuku and connects to Huapai (60 km/h). The change in speed limit (to 80 from 100 km/h) took effect 7 September 2020. Figure 2.2. shows that speeds were already quite low with the exception of the easternmost portion of SH16 (3300m east of Mabbett Lane). Average speeds on this section were 86 km/h (C85 was 96 km/h) which dropped to 83 km/h (C85 was 94 km/h) immediately following introduction of the new speed limit. Other speeds were already below 80 km/h, or 82 km/h in the case of Westbound SH16, 4400 m west of Old Railway Road. The speeds stayed low for the seven-week monitoring period, again with the exception of the eastern most portion of the road which although lower, still exceeded the new speed limit.



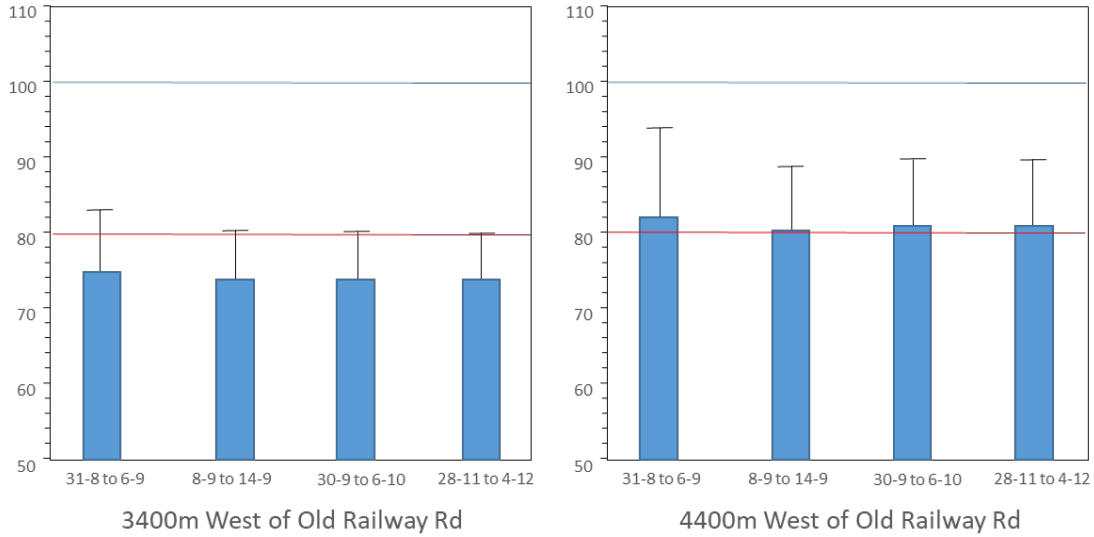


Figure 2.2. SH16 Eastbound (top panels) and Westbound (lower panels) Bars indicate C50 speeds at each date, and whiskers indicate C85. The first column of each graph show the free speeds prior to any speed limit change, subsequent bars show speeds after the change.

2.2.3. SH5 Waiotapu

Next SH5, which is a stretch of highway between Rotorua and Taupo that had its speed reduced from 100 km/h to 80 km/h following speed consultation with the general public on 6 September 2020. The data in Figure 2.3 suggests that, unlike SH3 and SH16, compliance with the new speed limit was poor on this road. As can be seen in Figure 2.3., the mean speeds here were 90 km/h Northbound. Immediately following the introduction of lower speed limit, the mean speeds increased to 92 km/h and the C85 speeds showed a 1 km increase (to 101 and 100). However, once the change had time to bed in (3 weeks), drivers appeared to adjust to their speeds downward closer to the new speed limit, driving at 86 and 89 km/h. At the end of the monitoring, seven weeks after the change, drivers were back to their original speeds or slightly faster.

The Southbound speeds followed much the same pattern, an initial increase in speeds, followed by a period of decreased speeds, before returning to their previous driving habits.

It's worth noting that that the mean speeds and C85 speeds actually increased over the original free flowing speeds at three of the four locations, despite the speed limit change.

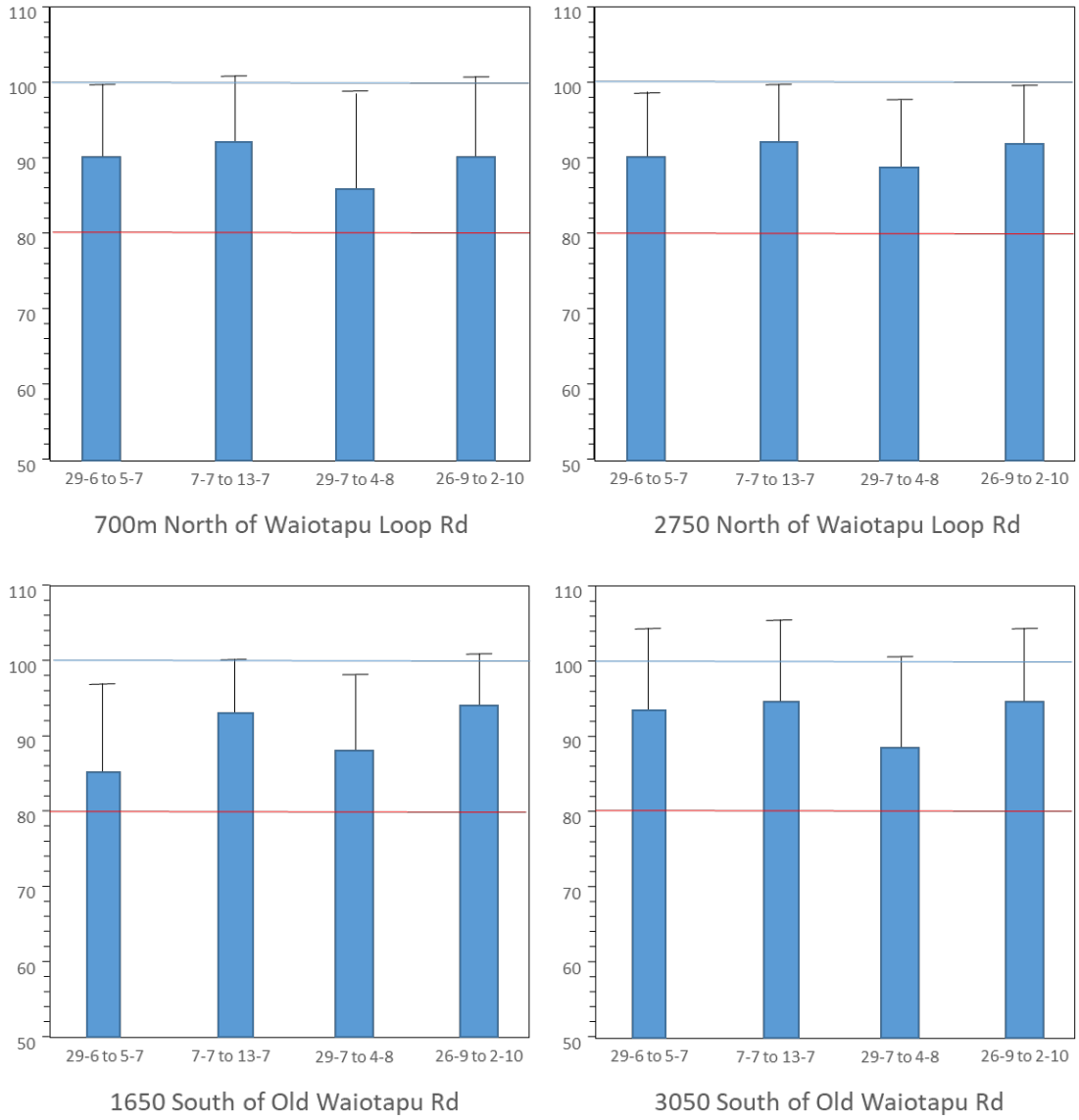


Figure 2.3. SH5 Northbound (top panels), and southbound (lower panels). Bars indicate C50 speeds at each date, and whiskers indicate C85. The first column of each graph show the free speeds prior to any speed limit change, subsequent bars show speeds after the change.

2.2.4. SH1 Pūhoi

In the north, SH1 just north of Pūhoi was discussed during community engagement in 2019. Construction of a major new stretch of highway between Pūhoi and Warkworth was taking place during the time of this research. Roadworks for that construction affected the speed data for vehicles travelling southbound, so they were not included in this study. However, speeds of vehicles travelling northbound were not affected and could be analysed in this sstudy. On 14 June 2021 the speed limits were reduced to 80 km/h (from 100 km/h). The sections of road depicted were not affected by the road works, and what can be seen (in Figure 2.4) is that speeds actually increased in the portion of the route near Pūhoi, although they began low (81 km/h rising to 83 km/h). The C85 speeds tracked this change and wound up 92 km/h. Average speeds for the northern section of road (closer to Warkworth) began higher (93 km/h) perhaps reflecting the open nature of the terrain (C85 was 103 km/h). The speeds here were reduced by the lowered speed limit, but never reached the new limit. The mean speeds on this section of road dropped 4 km/h by the end of monitoring (to 89 km/h) and the C85 speeds were still at 101 km/h.

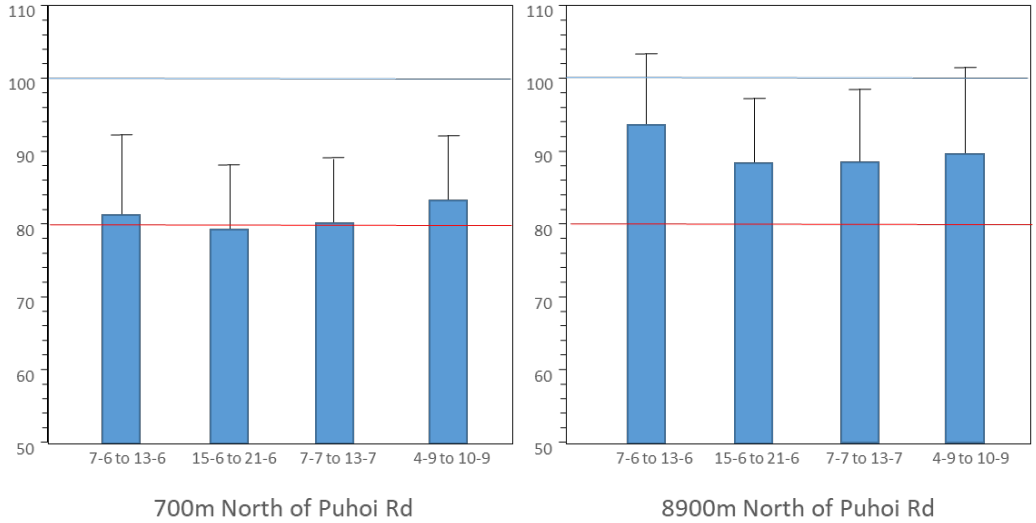
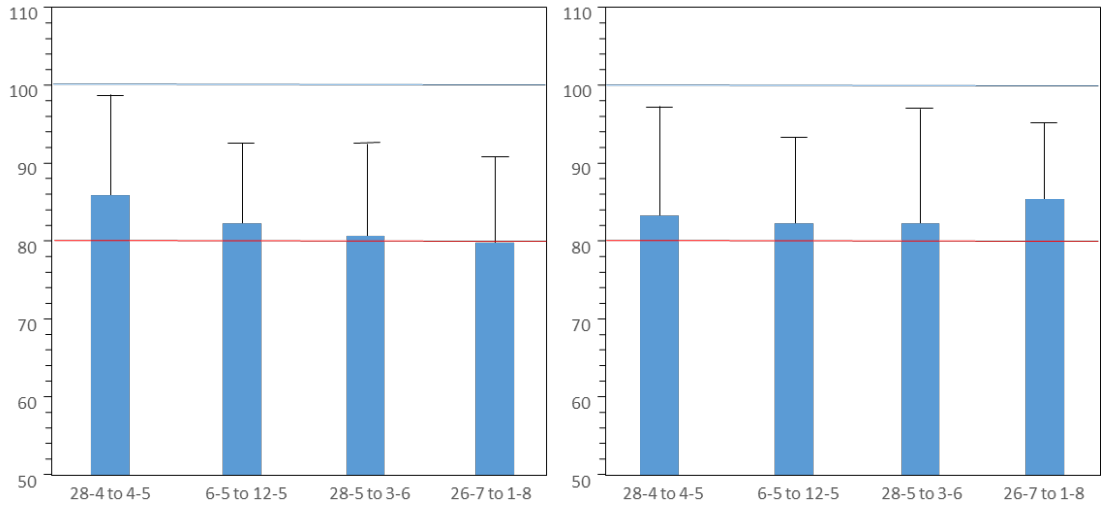


Figure 2.4. Speeds for SH1 Northbound at Pūhoi. Bars indicate C50 speeds at each date, and whiskers indicate C85. The first column of each graph show the free speeds prior to any speed limit change, subsequent bars show speeds after the change.

2.2.5. SH60 Tākaka

In the South Island, SH60 from Tākaka to Paines Ford (100 km/h), is a much-used tourist track with a seasonal speed limit (December and January) of 80 km/h. Public consultation on the appropriate speed limit for this road were held in September 2020, and effective 5 May 2021 this section underwent a speed limit reduction to 80 km/h year-round. Figure 2.5. shows the speeds for this road, and as shown, there was some reduction in speeds immediately (however small). By the end of the monitoring period, however, speeds had recovered at two of the locations, and had nearly recovered at a third. For the fourth location, 1600 m north of the river bridge, the speed had stabilised and was now 80 km/h (down from 86 km/h). The C85 speeds had decreased for all locations making them tighter distributions.



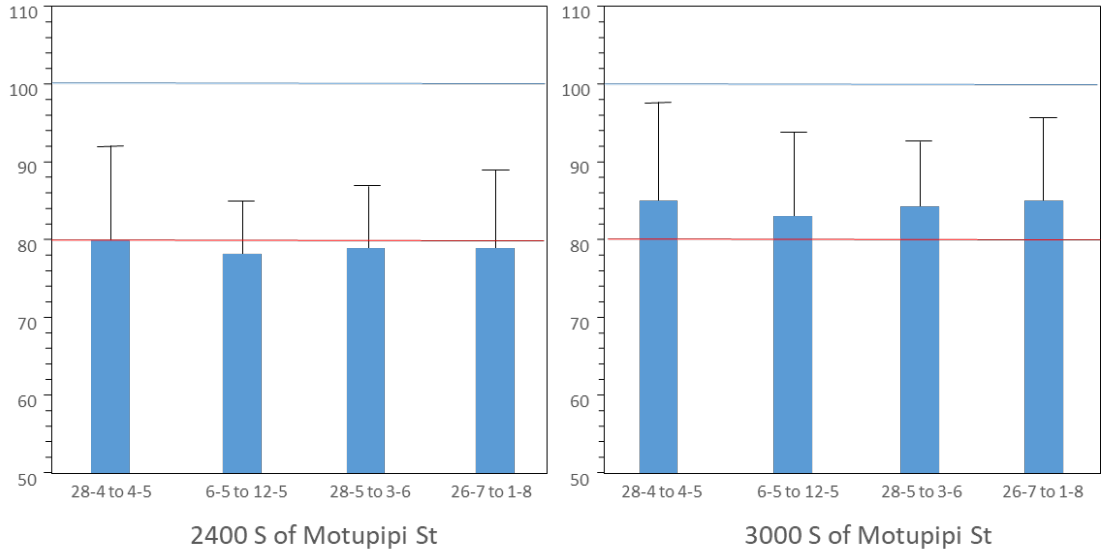


Figure 2.5. Speeds for SH60, Northbound (top panel) and Southbound (lower panel). Bars indicate C50 speeds at each date, and whiskers indicate C85. The first column of each graph show the free speeds prior to any speed limit change, subsequent bars show speeds after the change.

2.2.6. SH1 Templeton

Staying in the South Island, Dawson's Road to Templeton is a section of road to the south of Christchurch where roadworks (associated with the exit of the new Christchurch Southern Motorway) have held speeds down for two years. This road, SH1 immediately East of the motorway exit, had its speed reduced to 80 km/h (from 100 km/h) on 3 March 2021. As shown in Figure 2.6., the speed reduction of this road dropped from 84 to 81 km/h (C85 dropped 96 to 89 km/h) for eastbound traffic and 83 to 79 km/h westbound (C85 dropped from 92 to 85 km/h). While 3-4 km/h may not seem like a large change in speeds, the change was more or less instantaneous and long-lasting.

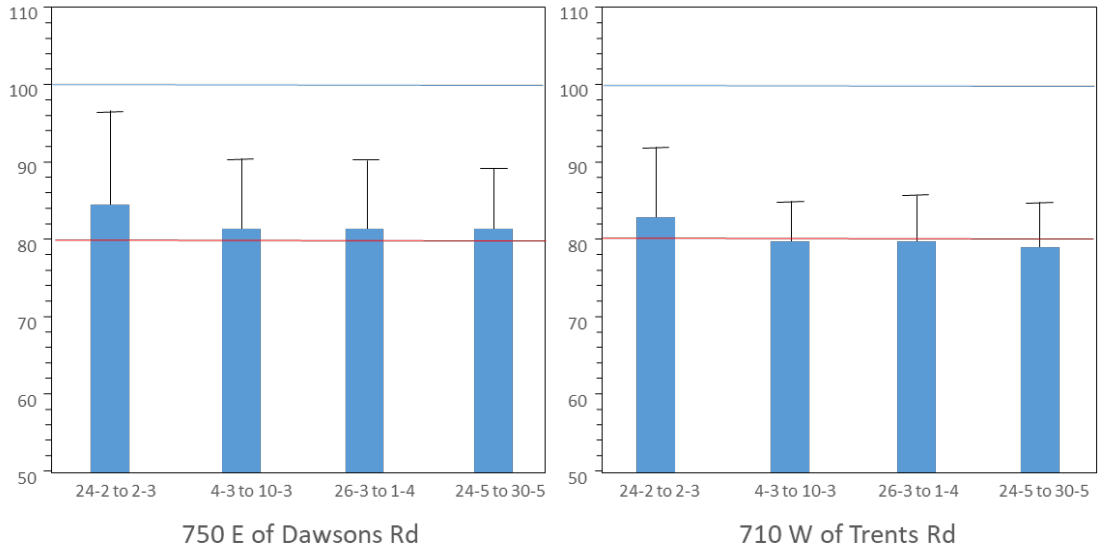


Figure 2.6. Speeds for SH1 Eastbound (left panel) and Westbound (right panel). Bars indicate C50 speeds at each date, and whiskers indicate C85. The first column of each graph show the free speeds prior to any speed limit change, subsequent bars show speeds after the change.

2.2.7. SH35 Te Puia Springs

Next we have a section of road for which the monitoring period was extended, albeit inadvertently. This gives us a chance to see how long-lasting the changes were on SH35 following speed limit reduction on 1 July 2021. Instead of the usual monitoring period of seven weeks, the end of monitoring extended out to nine weeks post change. As can be seen in Figure 2.7., there was an immediate drop in speeds following introduction of the new speed limit. By the end of the monitoring period however, speeds had returned to nearly their pre-intervention levels. The northbound sections recorded a speed of 84 km/h (from 85 km/h originally) and 82 km/h (from 85 km/h originally) by the end of the monitoring period. Heading southbound, the traffic recorded mean speeds to 86 km/h (from 85 km/h originally) and 82 km/h (from 85 km/h originally). It must be said that the speeds on this section of road were not significantly high, but the reduction in speed limit did not have the desired impact on vehicle speeds.

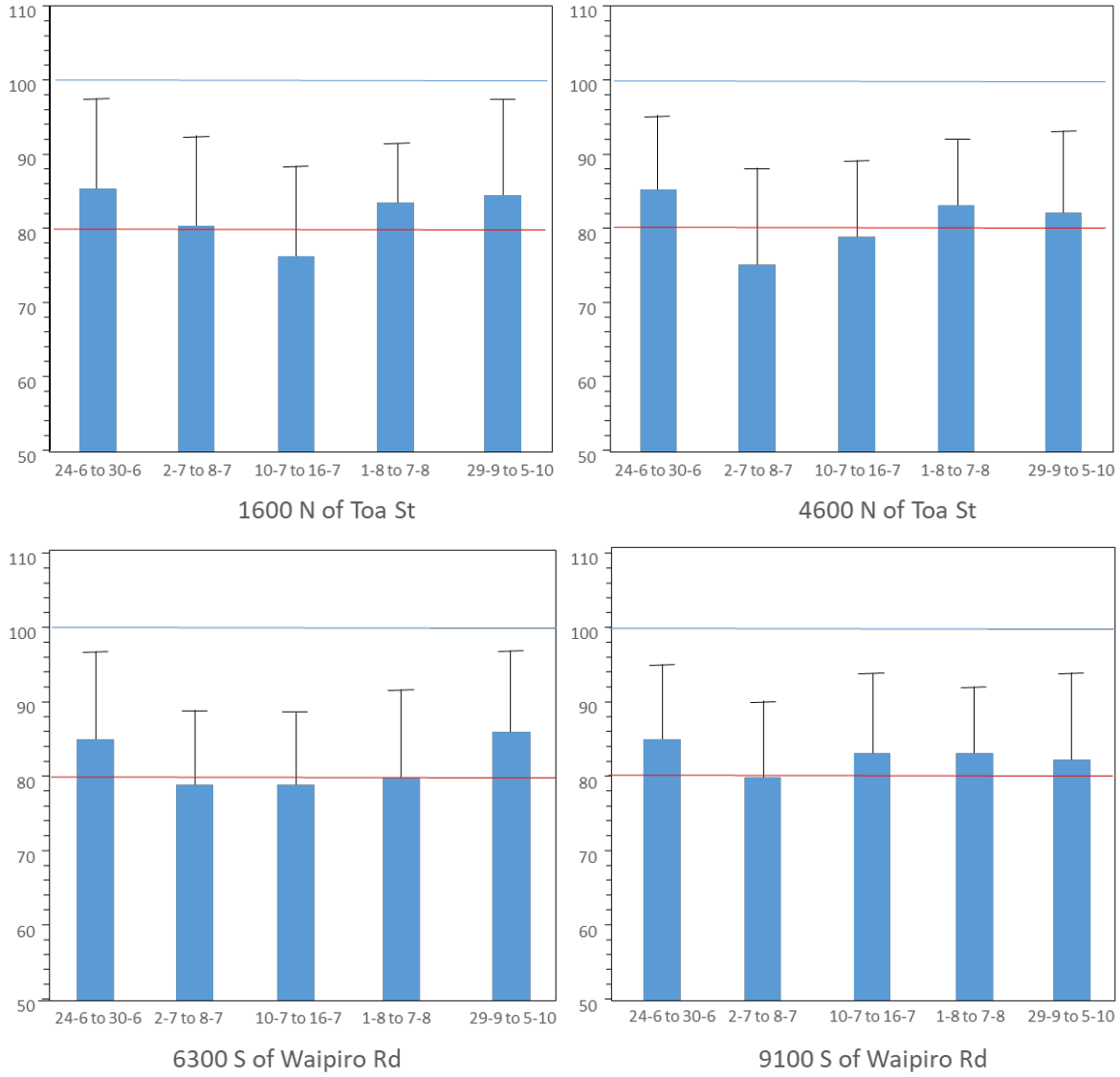


Figure 2.7. Speeds for SH35 Northbound (upper panels) and Southbound (lower panels) during the extended monitoring period. Bars indicate C50 speeds at each date, and whiskers indicate C85. The first column of each graph show the free speeds prior to any speed limit change, subsequent bars show speeds after the change.

2.2.8. SH22 Drury

Finally, we have the speeds for SH22 Drury to Paerata, specifically the section of road traveling between Oira Creek past the Pukekohe golf course. This section of road had its limits reduced on 30 June 2020, from 100 km/h to 80 km /h and Figure 2.8. shows the

resulting speeds. Mean speeds were well down, with the exception of the two middle sections; 4200 north of Crown Road and 5200 South of Burberry Road where they remained above the new speed limit (albeit lower than original speeds at these locations).

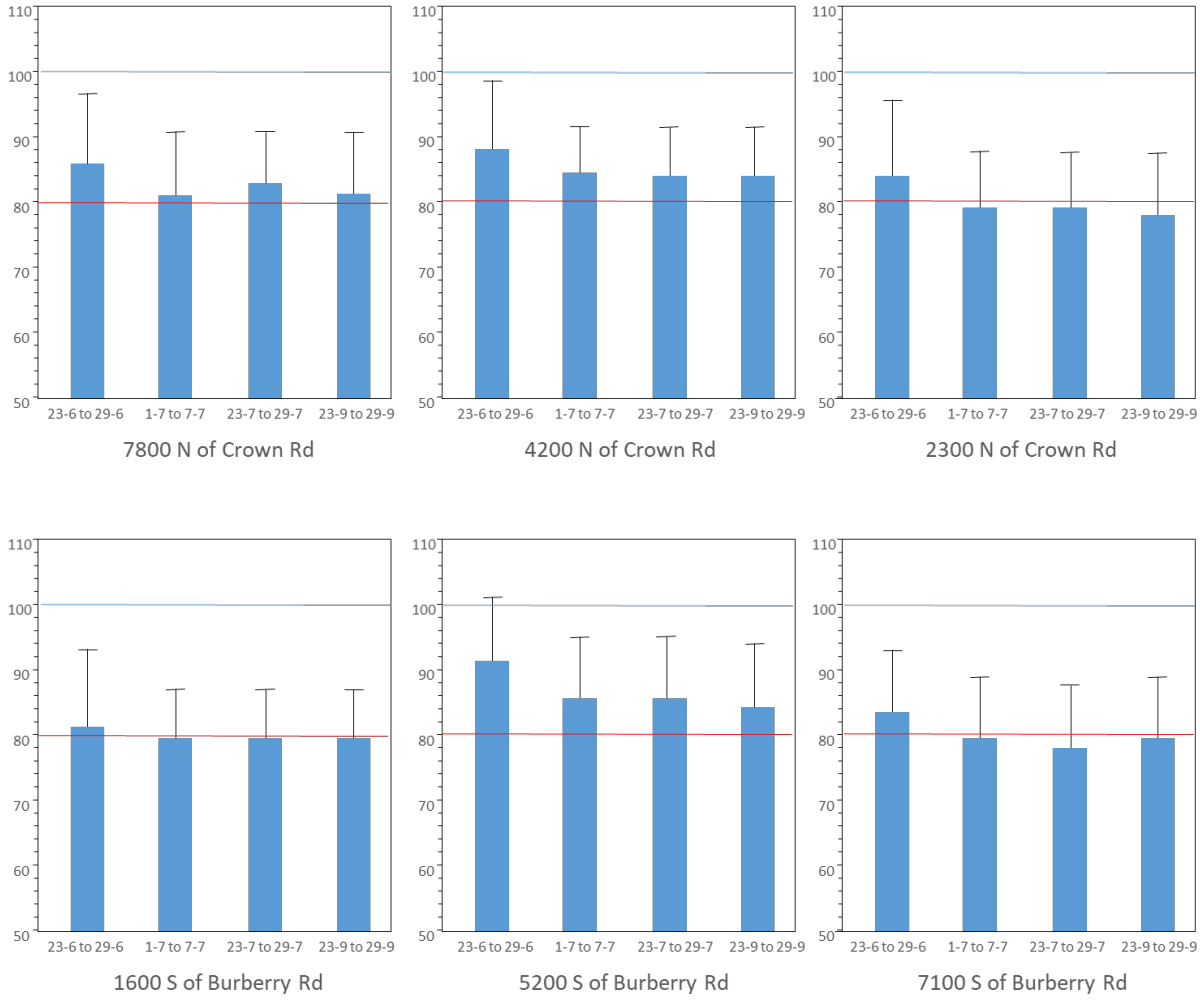


Figure 2.8. Speeds for SH22 Northbound (top panels) and Southbound (lower panels). Bars indicate C50 speeds at each date, and whiskers indicate C85. The first column of each graph show the free speeds prior to any speed limit change, subsequent bars show speeds after the change.

2.2.9. Summary and geometric data

Summarising the 30 sites sampled, 21 had mean speeds that were above 80 km/h at the end of monitoring and all of them had C85 speeds above the speed limit. Summary data are

presented in Table 2, the mean and C85 speeds are taken from the last week of monitoring the speeds. As can be seen in the figure, only eight of the locations had mean speeds 5+ km/h than the new speed limit.

Table 2. Locations and speeds from the speed monitoring. Mean speeds and C85 speeds are taken from the last week of monitoring.

Location		Mean speed	C85 speed	Location	Mean speed	C85 speed
SH3 Whanganui						
	680 E of Blueskin	82	93	1200 E of Blueskin	78	86
	1520 W of Virginia	78	84	2400 W of Virginia	82	89
SH16 Waimauku						
	3300 E of Mabbett	84	94	4400 E of Mabbett	77	87
	3400m W of Old Railway Rd	74	81	4400m W of Old Railway Rd	81	90
SH5 Waiotapu						
	700m N of Waiotapu Loop	90	101	2750m N of Waiotapu Loop	92	100
	1650m S of Old Waiotapu	94	101	3050m S of Old Waiotapu	94	104
SH1 Puhoi						
	700m N of Puhoi	83	92	8900m N of Puhoi	89	101
SH60 Tākaka						
	1600m N of Takaka River Bridge	80	91	100m N of Takaka River Bridge	85	95
	2400m S of Motupipi	79	89	3000m S of Motupipi	85	96
SH1 Templeton						
	750m E of Dawson's	81	89	710m W of Trent's Rd	79	85
SH35 Te Puhia Springs						
	1600 N of Toa	82	93	4600 N of Toa	84	97
	6300 S of Waipiro	86	97	9100 S of Waipiro	82	94
SH22 Drury						
	7800 N of Crown	81	91	4200 N of Crown	84	92
	2300 N of Crown	79	87	1600m S of Burberry	79	87
	5200m S of Burberry	84	94	7100m S of Burberry	79	89

While this is disappointing news, some geometric data are available for the above roads which may help explain why some of the roads were successful in implementing new speed

limits and others not. The roads at SH3 in Whanganui and SH22 Drury both showed immediate and sustained decreases in speed following the introduction of the new speed limits. These two roads both had relatively narrow paved surfaces, 10.5 m in the case of SH3 Whanganui, and 10 m in the case of SH22 Drury. It is a well-documented finding that as lane width and road width decrease, drivers' speeds also decrease (Godley, Fildes, Triggs, & Brown, 1999; de Waard, Steyvers, & Brookhuis, 2004). Although the lane width on these roads were not decreased, they were relatively narrow, and in the context of wider roads on the network that could have been the reason for the speed reductions. In the case of SH60 at Takaka, the paved surface was already narrow, 10 m, and this tourist destination, which already had seasonal speed limits of 80 km/h, was a qualified success. At SH16 Brigham Creek, the road was 13.3 m in width at the point that speeds were measured, with the exception of 3300m East of Mabbett Ln which had a paved surface of 14.6 m. Speeds were already higher on this section of road, and might be expected to creep upwards, nearly recovering their former speeds as time goes on.

The next two, SH5 at Waiotapu and SH1 at Puhoi, had some of the widest paved cross sections, 15.5 and 13.6 respectively, at the point of speed monitoring. In the case of SH5, it is a recently re-surfaced (29-4-21) section of highway, and represents a change to the rural character of the state highway North and South. This section of road had some of the highest speeds and proved very resistant to change with a simple speed limit sign (approximately 100 km/h C85 speeds). At SH1 Puhoi, the northernmost tracking site, the public were coming out of a section of roadworks (in the opposite lane) and were travelling at a mean speed of 89 km/h and the C85 speeds were still at 101 km/h.

Finally, SH35 at Te Puia Springs with a paved cross section of 8.5 m. This section of road had moderate speeds, which were reduced by the speed signs and stayed low until the last two monitoring periods. Recall that this stretch of road had extended monitoring

(unintentionally), and the speeds almost resumed their pre-intervention levels by the end. This stretch of road is rural and sparsely populated and despite its narrow cross section speeds were resistant to change. Part of the reason for this may be due to the sites selected for monitoring, straight sections of road which were interspersed with curvilinear portions. The recent flooding caused by cyclone Gabrielle brought considerable damage to the road, and one hopes that road works to remediate that damage do not cause increases in speed to occur.

2.3. Discussion

The results show that despite reductions in speed limits, many drivers in New Zealand continue to exceed these limits. Twenty-one of the sites had mean speeds that were above 80 km/h at the end of monitoring and all of them had C85 speeds above the speed limit. Many of the sites showed immediate and sustained decreases in speed and it would be a shame to mark these as a failure. That being said, even with the most generous of criteria for success, eight sites of the 30 reported on were less than successful.

Using mean speeds as an outcome measure can also be problematic in this context, as it can mask the variability in driver speeds and behaviours. For example, if a road has a posted speed limit of 80 km/h, but some drivers are driving at 70 km/h while others are driving at 90 km/h, the mean speed may appear to be within the legal limit, but the range of speeds may be large enough to create a dangerous situation. It can lead to a mismatch between the speeds of different vehicles on the road, which can increase the likelihood of accidents. For example, if some drivers are driving at high speeds while others are driving at lower speeds, it can create a dangerous situation where faster drivers are forced to swerve or brake suddenly to avoid colliding with slower vehicles. Additionally, drivers may feel frustrated or inconvenienced by the lower speed limit, particularly if they do not understand the reason for the change or if the

change is perceived as arbitrary or unnecessary. This frustration can lead to a reluctance to comply with the new speed limit, particularly if the driver perceives that the lower speed limit is not justified by the road conditions.

When some drivers are driving faster than the posted speed limit and others are driving slower, the risk of collisions increases significantly. This is because the speed differential between vehicles increases, making it difficult for drivers to anticipate each other's actions and react appropriately. Therefore, it is important to use other measures, such as the 85th percentile speed, to determine appropriate speed limits and to ensure that the majority of drivers are traveling at safe and consistent speeds. Overall, it is crucial to ensure that all drivers are traveling at safe and consistent speeds to minimize the risk of collisions and ensure the safety of all road users.

Particularly evident on high-speed roads such as highways and motorways, the consequences of high-speed driving include an increased risk of accidents and fatalities, as well as increased fuel consumption and environmental impact. The analysis of the data showed that there were still a significant number of drivers who maintained high speeds despite the lower limits. This is because they have become accustomed to that speed in that particular area and it has become a habit. This tendency to revert back to familiar speeds can be problematic, especially if the speed limit was lowered to improve safety. It can also lead to dangerous situations if other drivers have adapted to the lower speed limit and are driving at lower speeds, resulting in a mismatch between drivers' expectations and behaviours.

This finding, that the mental categories and expectations evoked by the look of a road can over-ride the presence of a speed limit sign, can be explored further by the inclusion of individual performance data. In a study of urban roads (Charlton and Starkey, 2017), participants drove a video-based simulation of familiar urban roads using the vehicle controls to speed up and slow down. When asked the speed limit on the roads they had just driven, the

participants were often wrong, choosing speeds that were consistent with roads that looked similar but had different speed limits. We believe that finding that drivers' ratings of their usual speed were the best predictor of their self-reported speeds suggests an influential role of habit in drivers' speed choices. In order to address the shortcomings of a lack of individual data and self-estimates of routine speeds, using a driving simulation has useful benefits. It can collect drivers' free speeds, in both urban and rural environments, as well as self-reported speeds and compare these against participants' speed limit beliefs and the actual speeds they chose to drive at. In the second study, the TRG University of Waikato driving simulator was employed to do just that, collect free speeds before and after a speed sign and identify participants' reasons for the speeds they chose.

3. Study 2

The other half of this study examines the persistence of drivers' habits and the speed limit anchoring effect. The speed limit anchoring effect is a cognitive bias that occurs when drivers use the posted speed limit as an anchor or reference point when deciding how fast to drive, and once decided they will not revisit the decision. Essentially, the anchor creates a mental bias that causes drivers to adjust their speed based on what they know is possible, rather that the posted limit, road conditions, and visibility. In New Zealand, the speed limit anchoring effect has been found to be a significant factor in determining driver behaviour on our roads (Ahie, Charlton, & Starkey, 2015; Charlton & Starkey, 2017). It appears that a driver's momentary choice of speed is often based on habit rather than resulting from an explicit decision. These habitual speed choices may be an inevitable consequence of repeated exposure to particular road and traffic conditions that result in the formation of schemata containing proceduralised or automatic ways of perceiving and driving on familiar roads.

That being said, the self-reported speeds, and beliefs regarding safe speeds surely have an effect on the efficacy of speed limits. This half of the study teases out those contributions to overall speed choice, and any awareness the participants might have regarding their own experiences with changes to the speed limits. Participants drove a series of roads in the simulator, and the speed limit sign did not appear, or did not appear immediately. During a planned break midway, and another break at the end of the driving sessions participants completed an on-line questionnaire that asked them some questions about safe speeds, how long it took them to adapt to a new speed limit, and what speed they currently drove on the road with changed speed limits. Finally, the questionnaire also contained several attitudinal statements about managing ones' speed while driving such as "*It is inconsiderate for people to drive slower than the speed limit*" and "*5 km/h above the speed limit is the real speed limit"* that participants had to agree or disagree with.

3.1. Method

3.1.1. Participants

Sixty-eight individuals with a full New Zealand driver's' license were recruited for the study via notices placed on community and university webpages and through direct email invitations to participants from previous simulator studies. Thirteen drivers withdrew from the study (due to eyestrain, dizziness or other discomfort) leaving a sample of 55 participants completing the study (34 females). The average age of these participants was 36.47 years (*SD* = 14.69, range 18-67 years). The participants reported holding a driver's license for an average of 19.09 years (*SD* = 14.18, range 2- 50 years). The ethnicity of the participants was 56.66% New Zealand European, 14.55% Maori, and 29.09% other (other European, Filipino, African, Japanese, etc).

Ethical approval for the recruitment and test protocols was received from the local research ethics review board. Participants received a $30 gift voucher in recognition of the time and trouble involved in their participation.

3.1.2. Simulation apparatus

The participants were seated in the Transport Research Group driving simulator consisting of a complete automobile (2010 Toyota Prius plug-in) positioned in front of three angled projection surfaces (see Figure 3.1). Participants' control actions (accelerator, brake, and steering) were recorded continuously via the vehicle CAN bus. The accelerator and brake pedals were standard and increased or decreased the speed of the video, and the equivalent vehicle speed (in km/h) was displayed on the digital dashboard speedometer. Moving the steering wheel produced a sensation of apparent steering by adjusting the position of the lane in real time. The lane position of the simulated vehicle could thus be moved to the right or left of the lane, but turns onto side streets could not be taken.

The driving simulator displays five screens of information representing 178.2 degrees forward field of view and approximately 100 rearward degrees field of view. Onto the screens the simulator presents video that has been specially recorded at 100 frames per sec so as not to skip at lower speeds. The simulator was static (fixed-base) and positioned in front of three angled projection surfaces. The centre projection surface was located 2.32m in front of the driver's eye position with two peripheral surfaces connected to the central surface at 52 ° angles. The three projection surfaces were angled back away from the driver at 4.3 degrees (from the bottom to the top of the projection surface). The centre projection surface was located 2.32 m in front of the driver's eye position and produced a 178.2 degree (horizontal) by 33.7 degree (vertical) forward view of the simulated roadway from the driver's position. The image projected on the central surface measured 2.6 m wide by 1.47 m high (at a resolution of 3840 by 2160 pixels) and each of the two peripheral images measured approximately 2.88 m by 2.15 m (at resolutions of 3840 by 2160 pixels). In addition, two colour LCDs with an active area of 12.065 cm by 7.493 cm each at a resolution of 640 by 480 pixels were mounted at the centre rear-view mirror and driver's wing mirror positions to provide views looking behind the driver's vehicle. Cameras were mounted behind the passenger seat and on the dashboard of the vehicle to record other aspects of the participants' behaviour during the experimental sessions. The projected images and vehicle model were updated at a minimum rate of 100 frames per second. Four speakers located inside the car and a sub-woofer in the rear cargo area presented realistic engine and road noises as appropriate.

Figure 3.1. The Transport Research Group driving simulator.

3.1.3. Simulation scenarios

For all of the participants, the simulation scenarios were divided into three blocks, Practice, Block 1, and Block 2, with a questionnaire between Block 1 and Block 2, and another after the end of Block 2. The scenarios began with a video of Papamoa Beach road in Papamoa shown at 46.82 km/h. The video immediately started slowing down, in accordance to the vehicle dynamics model, unless it received input from the driver (accelerator or brake). This was the practice drive and lasted approximately 60 sec. The practice drive was followed by a break in which questions could be asked and instructions were given to the participants. The next video in the chain, Block 1, was Karaka Road (SH22, Drury) which started at 79.19 km/h. The video chained automatically to Lake Moeraki (SH6, South Island) which started at

77.33 km/h; Collins Road (Hamilton) which started at 89.58 km/h; Takaka Valley Highway (SH60) which started at 78.89 km/h; Volcanic Loop Highway (SH1, Taupo) which started at 75.29 km/h; Ohaupo Road (SH3, Hamilton) which started at 82.86 km/h, Great North Rd (SH3, Whanganui) which began at 79.98 km/h; and Paerata Rd (SH22, Paerata) which began at 57.99 km/h. The starting speed for each of these road sections was taken from live footage as the camera car drove the route, which immediately started to decrease unless the participant pressed the accelerator.

Upon completion of the simulated drive, the participants were invited to complete the first questionnaire. The first block of roads took approximately 8.5 min to complete and the questionnaire took 5 minutes. After the first questionnaire the participants were re-seated in the simulator and they began the second drive. The Block 2 roads consisted of Queen Street, Auckland which began at 22.57 km/h; River Road Hamilton which began at 46.34 km/h; Taieri Plains Highway (SH1, Waihola) which started at 50.43 km/h; Hudson Street, Riverlea, Hamilton which started at 39.89 km/h; Barrington Drive, Huntington, Hamilton which started at 42.18 km/h; Symonds Street, Auckland which began at 21.09 km/h; Nixon Street, Hamilton East which started at 38.78 km/h; and Richmond Street Whitiora, Hamilton which began at 36.86 km/h. After completing the drive (8.5 minutes) participants were again invited out of the simulator and into the control room to compete the second on-line questionnaire (5 minutes).

3.1.4. Materials

The participants completed two questionnaires during the drive, the same questions were asked each time, beginning with a list of all the ways (good and bad) the recent speed changes will have affected drivers and whether or not they agreed with the changes. Then, six photos from the drive were shown, one at a time, and the participants were asked what speed they chose, did they change their speed during the drive (and by how much), what is a safe

speed for this stretch of road, and what they thought the speed limit was. During the second half of the questionnaire, photos from six of the roads were shown and the drivers were asked the same questions about them. They were also asked about a road they drove frequently that had its speed limit changed from 100 km/h to 80 km/h and how many drives it took them to adapt to the new speed limit (and if they did). They were asked how often they drive on that road, do they agree with the new speed limit, what speed they currently drive on that road, and what roadside features would make it easier. Then the questions were repeated for a road that was recently changed from 50 km/h to 30 or 40 km/h, they were asked the same questions as before. If participants could not recall a road which had its speed limit changed (either to 80 or 30/40 km/h), a printed reminder of roads in and around Hamilton was provided. Finally, they were asked to agree or disagree with a series of statements such as: *It is inconsiderate for people to drive slower than the speed limit*, and *Its good to drive below the speed limit*. The questionnaire ended with a series of demographic questions about the participant's age, gender, and their driving experience. A list of all the questions asked of the participants is presented in the appendix.

3.1.5. Procedure

At the start of each experimental session the participants completed an informed consent form and were allowed to ask any questions. The participants were seated in the driving simulator and took the short practice drive. Participants were told how to operate the simulator and to adjust the speed (using the accelerator and brake) to whatever speed they would choose if they were driving in their own car. They were also told to gently steer the simulated vehicle as they drove to make sure that they are looking at the road the same way they would in their own car. The participants were told to report if they felt dizzy or unwell at any point, because …*if you are not feeling well you will not be driving normally*. The participants completed both drives, the questionnaire, and were given $30 in gift vouchers.

3.2. Results

When asked to name some of the advantages and disadvantages of the new reduced speed limits, the majority of the participants (44, 80.0%) said that they believed the roads were safer, for both the Block 1 roads, as well as the Block 2 roads. An equal number said that they believed that travel times had increased (81.82% for high speed roads, 78.18% for the low speed roads in Block 2), although several participants said both that travel times had increased and decreased, for a total of 10.91% (on both blocks of roads). A total of 38 participants (69.09%) said that congestion had increased on both blocks of roads. A total of 30 (54.55%) said that more people are getting speeding tickets on Block 1 roads (40.0% of the participants indicated that this was the case for the Block 2 roads).

When asked if the road was more or less pleasant to drive on, 27.27% of the participants said the Block 1 roads were more pleasant, whereas 20.0% of them said that it was less enjoyable. For the low speed roads in Block 2, 45.45% said that the roads were more pleasant, while 25.45% said that the roads were less enjoyable. When asked did they agree with the reduced speed limits on Block 1 roads, 24 (43.64%) indicated that yes they did, whereas 19 (34.55%) said they did not, 12 (21.82%) were undecided or did not know. For the low speed roads in Block 2, 30 (54.55%) indicated that yes, they agreed with the new speed limits, 14 (25.45%) indicated that they did not, 11 (20.0%) were undecided or did not know.

For the next part of the questionnaire, participants were asked to imagine a road they knew well that had its speed limit changed from 100 down to 80 km/h. They were then asked how long it took to adapt to the new speed limit (i.e., chose the new speed automatically), the results are shown in Table 3. As shown in the table below, the greatest numbers of participants said that it took them between once to five times to adapt to the new speed limit. Fully 61.22% of the participants said this about the Block 1 roads, and 78.57% said this about the Block 2 roads. When asked if changes to the road or roadsides would help them make this

adjustment sooner for the Block 1 roads, 34 participants answered more signs (including electronic signs) and 10 participants answered road markings. For the Block 2 roads, 20 participants answered more signs, 16 answered road markings, and 4 answered road humps.

Table 3. Participants indicating the duration of their speed adaptation process.

	Block 1 roads	Percentage	Block 2 roads	Percentage
None I already drove that speed	4	8.16%	7	16.67%
Once or twice	18	36.73%	18	42.86%
Between two and five times	12	24.49%	15	35.71%
Ten or twenty times	8	16.33%	3	7.14%
More than twenty times	1	2.04%	1	2.38%
I still haven't adapted to the new speed limit.	2	4.08%	0	0%
Total	45		44	

To see if the statements lined up with actual speeds in the simulator, individual comparisons were made between the participants' estimates and their actual speeds. Figure 3.2 show two roads for which 80 km/h is the actual speed limit, Volcanic Loop Highway (SH1, Taupo) and Great North Road (SH3, outside of Wanganui). (For brevity, only three illustrative participants' simulator speeds are presented, one each from the beginning, middle, and end of the list of participants.) Participant 4 said they chose 100 km/h on the Volcanic Loop Highway (SH1, Taupo) and that they thought 100 km/h was a safe speed. Inspecting the top panel of Figure 3.2 shows that they correctly recalled the speed they chose. However, in spite of traveling 100 km/h for the first portion of the road, they said that they chose 80 km/h on Great North Road (SH3, Wanganui), that 80 km/h was a safe speed, and that 80 km/h was the correct speed limit. The 80 km/h speed limit undoubtedly made an impression, but they did

not have any recollection of changing their speed (*I did not intentionally change my speed*).

For the Volcanic Loop Highway (SH1, Taupo) Participant 34 (middle panel of the figure) said that they chose 100 km/h, that 100 km/h was a safe speed, but that 80 was probably the speed limit. For the Great North Road they said that they chose 80 km/h, that 80 km/h was a safe speed, but they said that the correct speed limit was probably 60 km/h, clearly misremembered.

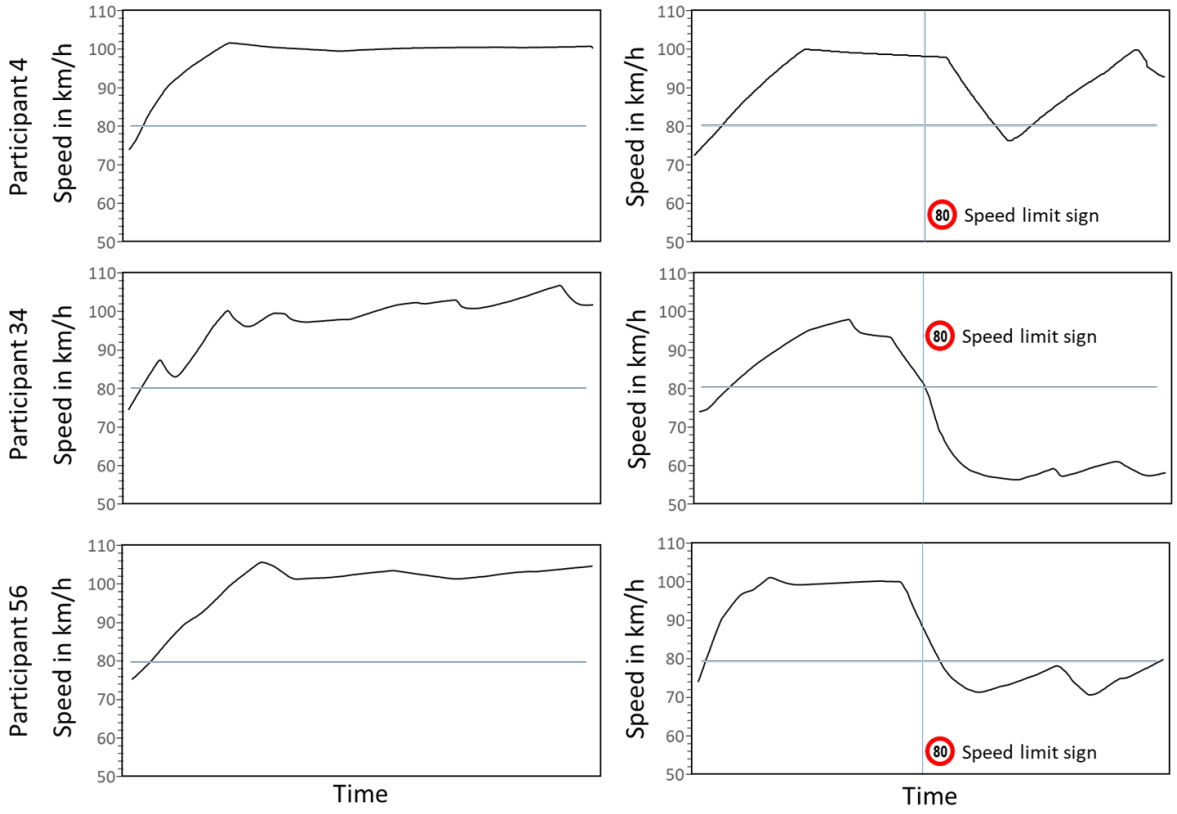


Figure 3.2. Three participant's speeds during SH1 outside Taupo (left side) and SH3 outside of Whanganui (right side). The road on the left has no speed signs along it, while the road shown on the right has one speed sign (80 km/h) midway through.

Participant 56 said that 100 km/h was the speed that chose, the safe speed, and the speed limit for the Volcanic Loop Highway (lower panel of the figure). For the Great North Road (SH3, Wanganui) the participant said that they chose 80 km/h, that 70 was a safe speed, and that the speed limit was likely to be 70 km/h. They had no recollection of choosing a higher speed,

and said they slowed down for houses around a town. Again, clearly misremembered for this road. In fact, of the speeds chosen by all participants for the Volcanic Loop Highway SH1, Taupo), 32 of them (58.18%) were in agreement with participants' recollections, 11 of them were lower than what they said they drove, and 12 were higher. Their recollection of the speed they chose during the drive was, however, significantly greater that the speed limit [M = 92.18, $t(54) = 9.594$, $p < .001$, $d = 1.294$], as was the actual speed [$M = 98.15$, $t(54) = 16.362$, $p < .001$, $d = 2.201$]. (Note: M is the mean speed, a positive value of t is indicative of a speed higher than the speed limit, a negative value of t indicates a choice lower than the speed limit.)

For the same speed limit on the Great North Road (SH3, Wanganui) participants said the same thing, 32 were in agreement with recollections, 11 were lower and 12 were higher. Comparing what they said, however, to what they actually did; significant numbers said they chose speeds lower than 80 km/h [$M = 66.73$, $t(54) = -6.656$, $p < .001$, $d = -.897$], and after the speed sign located half-way along the road they were correct, significant numbers did drive slower than 80 km/h [$M = 75.94$, $t(54) = -5.045$, $p < .001$, $d = -.680$]. For the section of road that preceded the speed limit sign, a significant number of participants drove faster than the posted speed limit [$M = 90.56$, $t(54) = 7.618$, $p < .001$, $d = 1.027$]. Participants didn't recall their faster speeds and claimed not to have changed their speed.

For another of the roads that participants may have been more familiar with, Ohaupo Road (SH3, Hamilton), participants overwhelmingly chose the correct speed. Forty-one of them said 80 km/h was the speed limit (74.55%), and 39 of them said they drove that speed or lower (70.9%) on the road. The Ohaupo Road clip had a speed sign half way along, and the average speed before the sign was 81.38 km/h [$t(54) = 1.453$, $p = .152$, $d = .196$], and after the speed limit sign averaged 80.17 [$t(54) = 0.453$, $p = .860$, $d = .024$].

For the low speed roads of Block 2 it was more difficult to draw conclusions because

performance was more variable. Shown in Figure 3.3 is Participant 4's speeds on six of the Block 2 roads. All of the roads had speed limits of 40 km/h except the first row shown, River Road and SH1 at Waihola, which had a speed limit of 50 km/h recently reduced from 60 km/h. As shown in the figure, speeds were more variable than during Block 1, the drops in speed shown for three of the roads, Hudson Street, Barrington Drive, and Nixon Street, were due to a stop sign located at Hudson, a roundabout near the start of Barrington, and a give way on Nixon. These three roads also were the only ones to have speed limits showing, speed roundels painted on Hudson and Barrington, and a speed sign on Nixon.

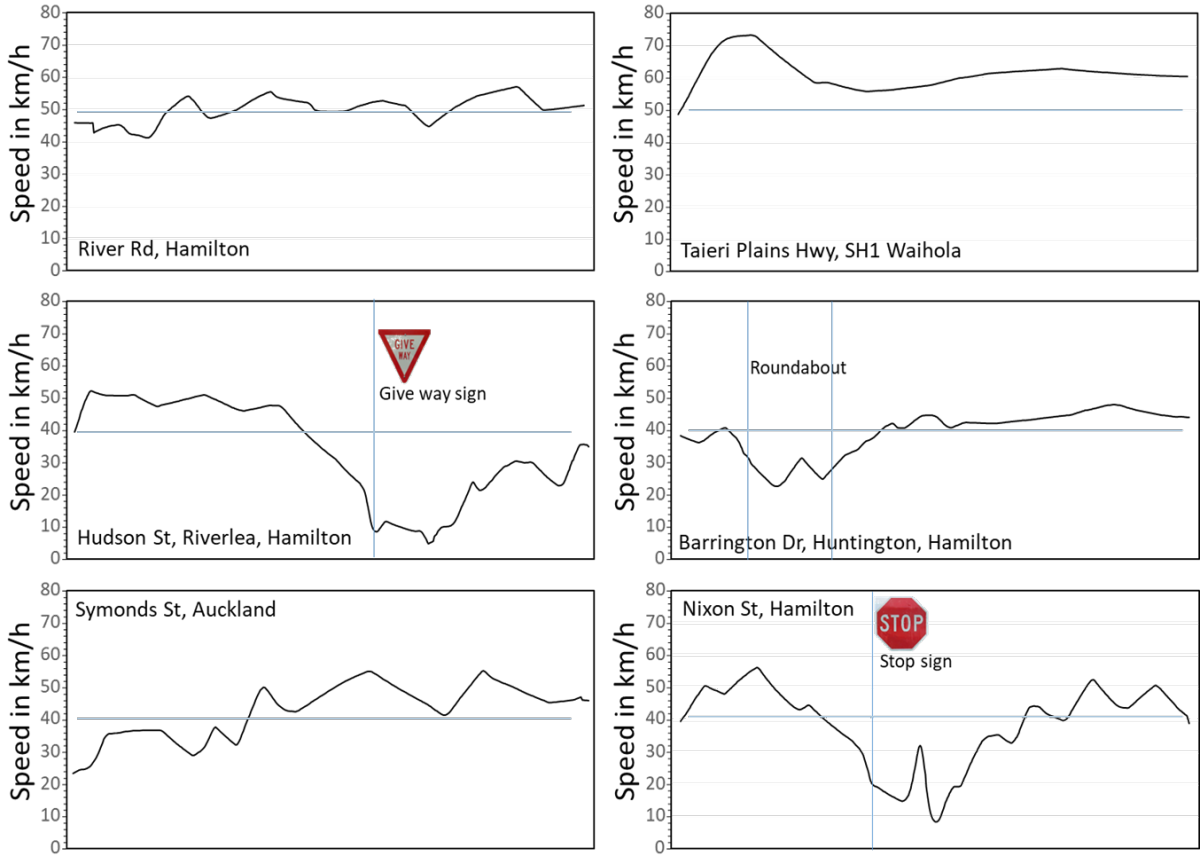


Figure 3.3. Participant four's speeds during the Block 2 roads. The roads at top have a speed limit of 50 km/h while all the others have a speed limit of 40 km/h. Speed limit signs were not visible except for roads 3, 4, and 6 which had speed roundels painted on the road for roads 3 and 4 and road 6 which had a speed sign posted midway. The dips in speed for these three roads are due to give way (3), stop (6) or roundabout (4).

Choosing a point approximately half-way along the roads to average speeds, speeds for River Road averaged 55.55 km/h and 56.89 for SH1 Waihola. In contrast, the mean choice for the

speed limit along River Road was 51.45 km/h and somewhat higher for SH1 Waihola, 55.82 km/h. Participants recollection of the speed they chose to drive at a speed of 54.73 on River Road and 58.82 on SH1 Waihola. Both of these estimates were significantly faster than the 50 km/h speed limit, [$t(54) = 4.405$, $p = .001$, $d = .594$ for River Road, and $t(54) = 6.032$, $p = .001$, $d = .813$ for SH1 Waihola]. Finally, the speeds driven of each of these roads were significantly faster than the 50 km/h speed limit [$t(54) = 6.016$, $p = .001$, $d = .811$ for River Road, and $t(54) = 7.666$, $p = .001$, $d = 1.034$ for SH1 Waihola].

Finally, Symonds Street, Auckland. The average of the participants' estimated speed limit was 43.09 km/h, which is pretty good for the 40 km/h actual speed limit [$t(54) = 2.817$, $p = .007$, $d = .380$]. Participants said they chose to drive 38.18 km/h, slightly below the speed limit [$t(54) = -1.695$, $p = .096$, $d = -.229$]. Participants actually drove 44.52 km/h, which was significantly faster than they had recalled, and the actual speed limit [$t(54) = 5.058$, $p < .001$, $d = .682$].

The questionnaire also asked several attitudinal questions about managing ones' speed. The results are shown in Table 4, and as can be seen opinions were uniform on some aspects and divided on others. The greatest agreement among participants came from three questions related to the maximum speed one should maintain on New Zealand roads. The statements "*I have to drive close to the posted speed limit*", "*5 km/h above the speed limit is the real speed limit*", and "*On most roads, its OK for good drivers to drive above the speed limit*" all had substantial agreement/disagreement, agreement with the first question and disagreement with the next two. Participants also disagreed with the statements "*I wish it were more acceptable to drive slower than the speed limit*", and "*It's good to drive below the speed limit*" indicating an intolerance for slow movers or inadequately tested speed limits. Similarly, agreement with the statement "*When road officials set the speed limit, it means they want everyone to drive at that speed on the road*" indicates that participants felt that speed limits were present to be

followed.

Table 4. Questionnaire responses to speed management questions.

	Number agree	Percentage	Number disagree	Percentage
It is inconsiderate for people to drive slower than the speed limit	33	60.00%	22	40.00%
The speed limit is not the speed we have to travel	28	50.91%	27	49.09%
I have to drive close to the posted speed limit	44	80.00%	11	20.00%
5 km/h above the speed limit is the real speed limit	12	21.82%	43	78.18%
It's good to drive below the speed limit	20	36.36%	35	63.64%
On most roads, it's OK for good drivers to drive above the speed limit	12	21.82%	43	78.18%
I wish it were more acceptable to drive slower than the speed limit	16	29.09%	39	70.91%
When road officials set the speed limit, it means they want everyone to drive at that speed on the road	37	67.27%	18	32.73%
When a speed limit is 100km/h, it's meant that people should drive between 80 - 100 km/h	25	45.45%	30	54.55%

3.3. Discussion

The results of the present study indicate that most participants said it takes them between one and five times to adapt to new speed limits. What is evident from their driving performance, however, is that they do not have a good recollection of their speeds on the open roads they experienced during Block 1. When asked the speed they drove on an unfamiliar open road they were more likely to choose 100 km/h. If an 80 km/h speed limit sign was present they said they drove 80 km/h, the correct speed limit, no matter what their speed was prior to the speed limit sign. For familiar roads the participants did recall the correct speed limit and chose correctly, driving at 80 km/h.

For low speed roads the situation was the same, the participants said they chose correct speeds for familiar roads, but generally drove a speed 10 km/h over the speed limit on unfamiliar roads. Of course, there was some element of wanting to appear good in what was a test of the speed limits set, but the participants were doing their best to recall the speed that they had actually driven during the on-road test.

What is apparent is that the participants said they wanted to be reminded of what the correct speed limit was, either with additional signs or some other cue such as road markings. The almost universal opinion was that roads with lower speed limits were safer to drive on, for both blocks of roads, and they agreed with the new speed limits. Regardless of whether they found the roads more pleasant, or less enjoyable to drive on, there was a consensus that the new speed limits had made the roads safer. This was borne out in the attitudinal questions about speed management, an overwhelming majority of participants said that they felt they had to drive close to the posted speed limit, and that they felt that road officials wanted everyone to drive to the speed limit.

4. General discussion

At the outset of this study we asked the question, how long does it take drivers to adapt to a reduced speed limit and what proportion of drivers do not adapt? Here, over the course of both studies, we found that speed adaptation collectively takes no longer than a week, if it's going to occur at all. In the first study, speeds at most sites were reduced substantially by the first week, a situation that held steady over most of the sites in the study. While speeds were reduced, that did not mean that all vehicles actually travelled at the new, lower speed limit. In fact, of 30 sites monitored only nine of them displayed mean speeds at or below the new speed limit (C85 speeds were above the new speed limit in all cases). We identified some geometric reasons for the high speeds, but suggested that the habit of driving at the previous higher speeds was responsible for much of what we saw (21 sites with mean speeds above the new speed limit).

When asked where to set the bar, how high is too high, we are faced with a conundrum. If we had obtained a mean of 80 km/h, fully one-half of the drivers would be exceeding the speed limit. When observed speeds are above the new speed limit of 80 km/h, clearly the new speed limit is not being adhered to. To know what proportion of the driving public is above the new lower speed limit we would have to have some indication of the standard deviation, a measure of speed dispersion. Unfortunately, those data were not available from the TomTom recordings. They were, however, available from the simulator data collected in the second study.

In the second study when asked how long it takes to adapt to a new speed, the bulk of participants said between one and five times, a result similar to the results observed for the speed surveys. When it comes to how many of the participants do not adapt, the answer depends on the absolute speed. In the second study 34.55% of participants said they were against the new speed limits on high speed roads, 24.45%, on the low speed roads. That does

not mean that proportion of drivers would break the law by driving too fast, it is simply the number of drivers who wish it were otherwise.

A somewhat better estimate can be derived from the questionnaire by looking at the number of participants who drove 100 km/h in an area they believed had a speed limit of 80 km/h; 7 out of 55 or 12.72%. Interestingly, the same number of participants, albeit not all of the same ones, said that they chose a higher speed that the speed limit on the low speed roads. Fortunately, we have the actual speeds that the participants chose during those roads. For the speeds chosen on three high speed roads we found actual speeds of 98.15, 90.56, and 81.37 km/h, depending on which road we are looking at (averaged across all 55 participants). The standard deviations for speeds on these roads was 8.25, 10.28, and 7.04. The standard deviation of 8.25 (combined with a mean speed of 98.15) means that only two of 55 drivers were at or below the new speed limit of 80 km/h. The standard deviation of 10.28 (for the speed of 90.56) is broader than the earlier standard deviation, and inspection of the data reveals that six drivers were at or below the new speed limit of 80 km/h. Of course, that is prior to the speed limit sign midway on the road. Post sign we observed a mean speed of 75.94 with a standard deviation of 5.97, and only nine of the participants were observed exceeding the 80 km/h speed limit at that point. For the mean speed of 81.37 and standard deviation of 7.04, we find that 24 of the participants were driving faster than the speed limit.

Clearly then, if we assume the standard deviation of speeds on the highway follows the same basic pattern as we obtained in the laboratory, the number of drivers speeding is too many. We could have achieved better compliance if we had introduced more signs leading up to the changed speed, and added some additional speed signs throughout, or at least that is what the participants said. In addition, placement of a speed zone appears to be critical. Placing a reduced speed limit at the first house, crossroads, or bridge strengthens the message that you are entering someplace different. Another aspect to be examined in this regard is the view

that speed limits are a target. Every kilometre per hour that someone is prevented from going represents a theft of their right to that speed, in essence a theft of their time. This is a peculiarly New Zealand sort of affliction, as seen in the answers to the attitudinal speed questions; participants said that they felt they had to drive close to the posted speed limit, and that they felt road officials wanted everyone to drive to the speed limit. It is doubtful whether residents of any European city would share that sentiment.

Taken together, the findings of the experiment generally support the idea that drivers do have a mental representation or schema for familiar types of roads. How a road looks to the driver seems to dictate their choice of speed at that moment. This supports previous work showing the importance of predictable road markings and other information informing the driver about the type of road they are on (Aarts & Davidse, 2007, Charlton & Starkey, 2017, Goldenbeld & van Schagen, 2007; Stelling-Konczak, Aarts, Duivenvoorden, & Goldenbeld, 2011). It suggests that an improvement in drivers' safety would result due to better selection of speeds. Systematic use of road signs and markings to indicate areas of hazard or reduced speed to drivers may provide an effective solution to improve road safety on some roads.

From another aspect the results are encouraging, we tested 55 participants and the overwhelming majority felt the new speed limits had made the road safer. That is, the participants agreed with the reduced speed limits and felt the need for additional speed signs that would keep themselves and others safe. Overall, this research suggests that if drivers were assisted to better recognise the speeds on rural and urban roads, an improvement in drivers' safety would result as a consequence of better speed choices.

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Appendix. Questions asked of the participants during Study 2.

Drive first half of roads – Block 1

On some of the roads you've seen, the speed limit has changed from 100km/h to 80 km/h

Please select all the ways, both good and bad, you think the changes will have affected drivers

- Travel times have increased
- Travel times have decreased
- Congestion has increased
- Congestion has decreased
- The road is safer
- The road is less safe
- The road is more pleasant to use
- The road is less enjoyable to drive on
- More people are getting speeding tickets
- Other (please describe):

Overall, do you agree with these changes?

- Yes
- No
- I don't know

Please answer the following four questions regarding the road in the above photo

What speed did you choose on this road?

Did you change your speed during the drive? If so, when and by how much?

What is a safe speed on this road?

What do you think the speed limit is on this road?

(Repeated 5 times for different photos)

Resume driving second half of roads – Block2

On some of the roads you have just seen, the speed limit has changed from 50km/h to 40 km/h, or from 50 km/h to 30 km/h

Please select all the ways, both good and bad, you think the changes will have affected drivers

- Travel times have increased
- Travel times have decreased
- Congestion has increased

Congestion has decreased
The road is safer
The road is less safe
The road is more pleasant to use
The road is less enjoyable to drive on
More people are getting speeding tickets
Other (please describe):

Overall, do you agree with these changes?
Yes
No
I don't know

Please answer the following four questions regarding the road in the above photo

What speed did you choose on this road?

Did you change your speed during the drive? If so, when and by how much?

What is a safe speed on this road?

What do you think the speed limit is on this road?

(Repeated 5 times for different photos)

Now we want you to think about a road that you frequently drive that recently had its speed limit changed from 100 to 80 km/h

Can you think of such a road?
Yes Name of road
No
If you can not, please ask us to help you think of an example before selecting no.

How long (how many drives) did it take you until you adapted to the new speed limit (i.e., you chose the new speed automatically)?
None, I already drove that speed
Once or twice
Between two and five times
Ten or twenty times
More than twenty times
I still haven't adapted to the new speed limit.

How often do you drive on that road?
Daily
More than once a week
Weekly
Monthly
Every 2 to 6 months
Yearly

Do you think the new speed limit on that road is appropriate? (and briefly tell us why)

What speed do you currently drive on that road?

What road or roadside features would make it easier for you to adapt to new speed limits on rural roads like these (e.g., additional signs, road markings, roadside changes)?

Now we want you to think about a road that you frequently drive that recently had its speed limit changed from 50 to 30 or 40 km/h

Can you think of such a road?
- Yes Name of road
- No

If you can not, please ask us to help you think of an example before selecting no.

How long (how many drives) did it take you until you adapted to the new speed limit (i.e., you chose the new speed automatically)?
- None, I already drove that speed
- Once or twice
- Between two and five times
- Ten or twenty times
- More than twenty times
- I still haven't adapted to the new speed limit.

How often do you drive on that road?
- Daily
- More than once a week
- Weekly
- Monthly
- Every 2 to 6 months
- Yearly

Do you think the new speed limit on that road is appropriate? (and briefly tell us why)

What speed do you currently drive on that road?

What road or roadside features would make it easier for you to adapt to new speed limits on rural roads like these (e.g., additional signs, road markings, roadside changes)?

Please select whether you agree or disagree with the following statements:

- It is inconsiderate for people to drive slower than the speed limit
- The speed limit is not the speed we have to travel
- I have to drive close to the posted speed limit
- 5 km/h above the speed limit is the real speed limit
- It's good to drive below the speed limit
- On most roads, it's OK for good drivers to drive above the speed limit
- I wish it were more acceptable to drive slower than the speed limit
- When road officials set the speed limit, it means they want everyone to drive at that

speed on the road
When a speed limit is 100km/h, it's meant that people should drive between 80 - 100 km/h

Now we want to ask a few questions about you

What is your age (in years)?

What gender do you most identify as?

Which ethnic groups do you belong to? Identify any that apply.
New Zealand European
Other European
Māori
Samoan
Tongan
Cook Islands Māori
Niuean
Chinese
Indian
Other (please state)
Prefer not to answer

Do you have a current driving license?
Yes
No
Prefer not to respond

What type of driving license?
NZ learners
NZ restricted
NZ full
NZ motorcycle
Overseas license
Prefer not to respond

How many years of driving experience do you have? (e.g., years since you passed your learners' test)