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The effects of operating a touch screen smartphone and other common activities performed while bicycling on cycling behaviour

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Keywords:

smartphone; touch screen; mobile gaming; bicycling; music; mobile phone; traffic safety

Highlights:

- We compared the effects of operating a touch screen phone to the effects of operating a conventional phone on bicycling performance
- We also studied the effects of gaming and talking to a companion on a bicycle
- Operating any phone leads to slower cycling speed, fewer objects being detected in the periphery, and a more central position in the cycle lane
- Performance on detecting objects is worse and lane position is more leftwards while operating a touch screen phone compared with a conventional mobile phone

Abstract

Although it has been shown that making phone calls or sending text messages while riding a bicycle can have a negative impact on bicyclist's behaviour, in countries such as the Netherlands the operation of a mobile phone while cycling on a bicycle is not illegal and is actually quite common. In recent years conventional mobile phones with a physical keypad are increasingly being replaced by smartphones with a touch screen. The operation of a touch screen phone ironically cannot be done purely 'by touch' due to the lack of tactile feedback, and instead requires fixations on a relatively small screen. The question therefore can be asked whether the operation of touch screen telephones deteriorates cycling behaviour more than operation of a conventional mobile phone. Twenty-four participants completed a track on their own bicycle while sending a text message from a conventional and a touch screen mobile phone. In addition the effects of other common activities that can accompany bicycling were studied, including texting at the same time as listening to music, talking on a mobile phone or cycling next to someone and speaking with this companion, and playing a game on a touch screen phone while bicycling. The impacts of all the above conditions on cycling performance and visual detection performance were compared with control conditions in which participants cycled with either one or two hands on the handlebars and were not required to perform any secondary tasks.

Bicycle speed was reduced in all telephone conditions and in the condition when cycling next to someone. Lateral position variation increased in all telephone conditions. Use of the touch screen led to a more central position in the cycle lane and resulted in worse

visual detection performance compared with the operation of a conventional mobile phone. The main effect of listening to music was that an auditory signal to stop cycling was missed by 83% of the participants. In conclusion, while all investigated types of phone deteriorated cycling performance, the use of a touch phone has a larger negative effect on cycling performance than a conventional mobile phone. With touch screen smartphones taking the place of conventional mobile phones and being used for other purposes than verbal communication, these effects on cycling performance pose a threat to traffic safety.

1. Introduction

In countries such as the Netherlands the use of a mobile phone and other electronic devices while riding a bicycle is quite common (Goldenbeld et al., 2012) and,in particular, making phone calls and listening to music while riding are common activities and are performed by 17% of cyclists [FOOTNOTE: In this paper both bicycling and cycling refer to riding a bicycle, not a motorcycle] during almost every trip they make (Goldenbeld et al., 2012). In an observation study in the Dutch city of Groningen almost 3% of the cyclists operated their phone while riding their bicycle (De Waard et al., 2010). In another Dutch city, The Hague, Terzano (2013) found that 3.5% of the bicyclists operated a mobile phone while cycling. She also observed that bicyclists performing secondary tasks while cycling exhibited more frequently dangerous behaviour, an effect also observed for cyclists who were talking with other cyclists. Furthermore, even in countries where the use of a mobile phone while cycling is prohibited, such as in Japan, cyclists can still be observed operating their mobile phones (Ichikawa & Nakahara, 2008).

Given what is known about the negative impact of mobile phone use on driving performance (e.g. Caird et al., 2008, Collet et al., 2010) the aforementioned prevalence of phone use while cycling is worrying in terms of the potential impact on the cycling performance and safety of bicyclists. As such, the effects of having a conversation on a mobile phone and of typing a text message on cycling behaviour specifically were studied a few years ago by De Waard et al. (2010). In this study it was found that bicyclists cycled at a slower speed when talking on the phone or when sending a text message. Furthermore, even though they cycled slower, the cyclists using a mobile phone also reported experiencing higher risk and mental effort, missed more visual stimuli from the periphery, and swerved more within the bike path, particularly when texting. In a further study in this area (De Waard et al., 2011), in which the use of a handsfree device while cycling was investigated, only limited advantages were found for handsfree phone operation. Independently of whether a handsfree or handsheld device was used the bicyclists tested cycled at a lower speed and missed more peripheral stimuli when talking on a mobile phone (De Waard et al., 2011). The only real advantage of handsfree, as opposed to handsheld, mobile phone use while cycling was that the speed in which a cyclist could come to a standstill after hearing an auditory signal to stop was faster when using a handsfree device, a finding that is likely related to being able to easily use both hands on the brakes. The effects of listening to music while cycling were also investigated in the same study (De Waard et al., 2011) and were found to have only limited effects on bicyclists' behaviour, with the exception of responding to a stop sound signal, which was frequently not heard, especially when wearing in-ear headphones.

All of the aforementioned research was carried out with traditional mobile phones with a physical keypad. In recent years, however, touch screen based phones have become more and more common. As the keys presented on a touch screen cannot be felt tactically, fixation on the screen is more often required to operate a touch based keypad. That one is more likely to have to look at a touch based keypad means that data entry is likely visually more demanding than a using a physical keypad, where touch typing is a more viable option, and thus there may be flow on effects to other behaviours that are performed in parallel. As such, when moving and processing information from the environment, as is required when riding a bicycle, operating a touch screen telephone may have a larger influence on bicycle control than a conventional mobile phone.

A major difference between conventional and touch screen phones is the tactile feedback these devices provide when entering information. More force has to be applied on conventional phone keypads and the location of the controls are fixed and often marked by tactile indicators similar to those on a computer keyboard, meaning that if needed the location of keys can be determined by touch. This is not the case with touch screen telephones, as the flexible mapping of information and controls on these screens is a key property of these devices and they are completely lacking in any tactile feedback that allows for easy touch only based operation. This means that while operating a touch screen based phone more visual attention is required (e.g., Burnett & Porter, 2001). With regard to the effects of using a touch screen device on bicycling performance, no studies have been found in the literature. Results from an on-line study however, indicate that in the UK, the USA, Belgium, and the Netherlands, up to 20% of the smartphone owners use their device while cycling (InSites Consulting Inc., 2012).

Touch-control operation is common nowadays in many motorised vehicles, e.g. in In Vehicle Information Systems (IVIS) such as navigation devices, or in other in-car systems (e.g., Jamson & Merat, 2005). In a moving vehicle the operation of touch screen devices has been shown to increase workload and to deteriorate input performance (Salmon et al., 2011, Goode, Lenné, & Salmon, 2012), however in these studies participants did not drive the vehicle and only operated a touch screen device while seated in the passenger seat. This means that in those studies only the direct effects of moving on being able to aim at and operate a touch screen were taken into consideration, and not the potential negative effects of having to divide attention between operating the device and driving. There are, in fact, only a few studies in which the operation of a touch screen device while driving has been compared with other input controls, all of which were performed in driving simulators (Rydström et al., 2011, Harvey et al., 2011), with the exception of one large European study (see Carsten & Brookhuis, 2005). For example, Rydström et al. (2011) compared the effects of operating a physical rotary control interface while driving with operating a touch screen interface while driving in a driving simulator. Alphanumerical tasks were found to be the most demanding but could be best completed with a touch screen interface. However, lateral control deteriorated more when the drivers operated a touch screen. These results are in accordance with those reported by Harvey et al. (2011) who also found that lateral control in driving, in a simulator, was more strongly affected by entering information on a touch screen than via physical controls. Given the currently limited state of research in the area how and why the operation of different types of input for mobile phones will affect driving and cycling behaviour is not yet clear.

Another issue is that smartphones, particularly those with touch screens, are used for more than just making and taking phone calls and text messages. Rather they allow their owners to use various applications, access the internet, and play games while on the move. The mobile gaming market in particular is booming at the moment (e.g. TG Daily, 2011), however, there is very little information available on whether people play games on a mobile device while driving a car or riding a bicycle. Another online study, “Popcap Games Mobile Gaming Research” (Popcap, 2012) reported some data from the USA and UK on playing mobile games while driving a car, but unfortunately this category is integrated with people who play games in a place of worship, and/or while they are watching a movie at a theatre. Still, articles in the popular media seem to indicate that gaming while cycling is a growing problem, particularly for children (VARA, 2012). If games are played on a smartphone with a touch screen while cycling, then this may enhance the potential negative effects of both game playing and touch screen operation on traffic safety.

Not all cyclists cycle alone, and cycling with a companion and talking with this companion is quite common. While the impact of cycling with a companion has not been well studied the effects could be comparable to talking with an in car passenger, which has been shown to be detrimental in terms of effects on driving performance, in particular on reaction time (Caird et al., 2008, Collet et al., 2010). Furthermore, merely having a passenger in a car has also found to be associated with an increased likelihood of an accident, although the effect was smaller than the effect of operating a mobile phone (McEvoy et al., 2007). In cycling there is also the risk that any increase in swerving related to a conversation may lead to a collision between the bicyclists, perhaps resulting in a fall and injuries. Some support for this idea can be found in a questionnaire study (Ormel, Klein Wolt, & den Hertog, 2009), that was carried out with people who had been treated in an Emergency Care Department after having had a bicycle accident. This questionnaire found that a relatively large number of cyclists (114 out of 1043, i.e. 11%) reported to have been talking with another cyclist when they had the accident.

In sum, effects of sending text messages and calling with a mobile phone while cycling have been found in the past, however, the question is whether these effects are larger if people have to handle a smartphone with touch screen versus a conventional phone with a keypad. An additional topic that has not been studied is whether playing games on a touch screen smartphone while cycling has negative effects on cycling performance, and how these effects compare to the effects of sending text messages. Finally, the question can be asked if talking on a telephone and talking to a cycling companion have similar effects on cycling performance or if they differ in terms of their impact on cyclist performance.

In the present study, the effects of using a conventional and a smart phone mobile phone while riding a bicycle on an isolated cycle path were studied. The type of phone, a conventional phone with keypad and a smartphone with touch screen, and the task performed were varied. The secondary tasks that had to be performed were texting, calling, talking, playing a game on a smartphone, and listening to music while texting. Texting was performed on both types of phone, the other tasks only on the touch screen smartphone. It is expected that the operation of mobile phones worsens cycling performance, particularly if a smartphone with touch screen is operated, as operating the touch screen may demand more visual attention than a conventional phone. More specifically, behavioural adaptation in the form of reduced speed is expected from the participants. The divided attention between cycling and the secondary tasks is also predicted to decrease lateral control, reduce the detection of objects in the visual periphery, and increase the response time to an auditory stop signal.

2. Method

2.1 Participants

Participants were recruited via word of mouth. They were asked to participate with their own bicycle and taking part in the experiment took around 60 minutes. Before the experiment started all participants provided written informed consent and after participation they received € 10 as compensation. In total 24 cyclists participated.

Ethics approval for this study was granted by the University of Groningen Psychology Ethics Committee. The participants were informed that their information would be treated anonymously and that they could withdraw from the experiment at any time with no penalty.

2.2 Location, conditions, equipment, and stimuli

The experiment was carried out on a quiet, somewhat remote, public cycle path (the same location as used in De Waard et al., 2010 & 2011), during dry weather. The use of such an isolated cycle path was demanded by the University of Groningen Psychology Ethics Committee for approval of the study. A bicycle helmet was also made available for use and offered to participants, but helmet use was not mandatory as very few cyclists in the Netherlands wear a helmet. The cycle path was 220 metres long and 1.92 metres wide (not far off the normal width of 2 metres for single direction bicycle paths in the

Netherlands, CROW, 2007) and participants only started a ride if no other cyclists were present. Each participant started their ride at the beginning of the cycle path, turned right at the end of the cycle path and then continued for about 30 metres on a normal asphalt road. On this final asphalt road segment of the track a stop-task was carried out (see section 2.2.1).

A within-subjects design was used and all participants completed all conditions once. After each condition the participants rode back on the other side of the road to the starting point. To avoid carry-over and practice effects the order of the conditions was balanced between participants according to a Williams design (Williams, 1949).

2.2.1 Mobile phones and tasks

Two mobile phones were used, a conventional phone with a keypad (Sony Ericsson K320i) and a touch screen smartphone (Sony Ericsson Xperia X8). All conditions included in the experiment are summarised and listed for reference in Table 1.

In the Text message conditions (TC, TT, and TTM, Table 1) participants had to type a well-known Dutch birthday song “Lang zal ze leven, lang zal ze leven, lang zal ze leven in de gloria”. Participants were asked to start typing the text anew should they manage to finalise typing it during the appropriate conditions. They were not allowed to make use of text support (e.g. T9, text on nine keys) on the conventional phone and on the smartphone a touch screen based ‘qwerty’- keyboard had to be used, again without predictive texting.

In condition HH participants were called by the experimenter and they answered the phone. In the CC condition the experimenter matched the participant’s cycle speed and rode to the left of the participant. In both the HH and the CC condition the participants had to perform a verbal task (a word game) where the last letter of the last word heard had to be used to verbally produce a word using this last letter as the starting letter of a word from the same category. Dutch cities, animals, or vegetables/fruit were used as words. So, for example, the experimenter (either on the phone or when cycling next to the participant) would start with “dog” and the participant could answer with “gorilla” and then the other would say “ant” and so on. Both the participant and experimenter had to answer as quickly as possible, but there were no time constraints. Rather, the main goal was to keep participants mentally loaded with this secondary task while talking on the phone or to the companion cyclist.

In the TTM condition participants wore in-ear headphones (Sony MDR ex 35 LP) and were allowed to select the song they liked best from a list of eight songs. They were also asked to put the volume at their preferred level (i.e., the volume level they normally listen to music while cycling). During the ride they were also required to send the birthday song text message.

In the game condition the game “Snake II” was used on the smartphone. The game was played at a low (thus slow) level. Playing the game required the participant to touch the screen before an on screen snake reached the border of the screen, or before it collided with a part of itself, to change the direction of movement of the snake. The snake would increase in length with increased playing time, making the game more demanding.

Before the experimental rides the participants had ample time to get familiar with both phones and to experiment with entering text. During the rides participants were asked to operate the phone with their preferred hand and to always give priority to safe cycling. Secondary task performance on the gaming and texting tasks were not analysed separately, however, it was checked whether participants had actually attempted this additional task.

>> INSERT TABLE 1 about here

Participants used their own bicycle, which in all cases was a type of town bike (European city bike). Upon arrival the participants received general information about the procedure and filled out an informed consent form. A GPS device (Garmin Forerunner 405) was then attached to the handlebars of their bicycle and the GPS coordinates were later used to derive their cycling speed. No particular instructions with regard to cycle speed were given, only that the participant should cycle as they would normally do.

At the end of each ride one of the experimenters honked a horn (100 dB measured from 5 metres distance). The operation of the horn was not visible to the participant. Participants were instructed to stop and put one foot on the ground as quickly as possible when they heard the horn. Stopping time was measured with a stopwatch starting at the time the horn was sounded and stopping when the participants came to a full stop with at least one foot on the ground.

During each condition the experimenters unobtrusively placed three objects on the ground at changing locations along the straight section of the cycle path. The objects were printed traffic signs (such as a priority road sign) or traffic lights on A4 size paper sheets protected with plastic. Participants were not instructed to search for the objects, but after each ride they were asked whether they had noted anything. The number of objects correctly identified, if any, was then written down.

2.3 Measures

2.3.1 Performance

Four performance measures were assessed: speed, lateral control, reaction time, and visual perception. The average speed in km/h on the straight segment was calculated from the GPS data. The GPS device sampled GPS co-ordinates at a rate of 0.5 Hz.

Lateral position control was assessed on the basis of video recordings that were made of each ride. To do so, a video camera was attached to fixed position on a nearby lamp post with a view of the cycle track. Then during analysis an overlay was used to divide the cycle path into nine “strips” each 0.213 m wide. The strip in which the front wheel was located was scored offline at 2 Hz (see Figure 1) and the average and standard deviation of lateral position was calculated. In total, for each ride, a fixed area covering 250 metres cycling position was scored. Depending on the speed of the cyclist this area was passed in 4 to 5 seconds, leading to 8 to 10 lane position samples per condition

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Insert Figure 1 about here
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As mentioned above, reaction and brake time were measured with a stopwatch from the moment the horn sounded until the participant came to a complete standstill with at least one foot on the ground. Finally, visual (peripheral) detection was assessed as the number of signs correctly named at the end of each drive.

2.3.2 Self-reported measures of mental workload and experienced risk

After each condition a mental workload rating on the Rating Scale Mental Effort (RSME, Zijlstra, 1993) was taken. The RSME is a unidimensional scale which ranges from 0 to 150. A rating of 12 denotes “almost no effort”, 58 is marked as “rather much effort”, and 112 as “extreme effort”. An estimate of experienced risk was also assessed; on the same scale where the word “risk” was substituted for “effort” (this same risk scale has been used in previous studies, see De Waard et al., 2010, 2011). After all conditions were completed, general information about cycling experience and habits concerning telephoning and listening to music while cycling were collected.

2.4 Analyses

Statistical analyses were performed with SPSS 18.0.3 for Windows. Alpha was set at .05. Repeated measures GLM (General Linear Model) procedures were applied to the continuous variables, such as speed. Hotelling’s T will be reported, and on post hoc contrasts to compare conditions a Bonferroni correction was used. The ordinal variables, such as number of objects detected, were evaluated with a Friedman test. If statistically significant differences were found between the ordinal variables then pair-wise comparisons for the relevant parameters were performed with a Wilcoxon signed rank test.

3. Results

3.1 Participants

Seven men (M = 24.3 years, SD = 4.3, range 20-31) and seventeen women (M = 21.5 years, SD = 1.8, range 19-25) completed the experiment. The average age of the participants was 22 years (SD 2.96). Six participants owned a conventional phone with keypad, two had a smartphone without touch screen, and 16 had a smartphone with a touch screen. The majority reported that they do initiate calls during cycling (15), and thirteen reported that they answered calls while cycling. Of the others, three stopped to initiate or answer calls but then continued to cycle while talking, and one participant reported that they use voice activation features on their phone to call while cycling. Nineteen of the participants reported that they send and read text messages while cycling.

In terms of their music listening habits, all but one participant reported that they listen to music while cycling, of these sixteen use two earphones, six use only one earphone, and one participant reported using full over ear headphones. None of the participants stated that they played games on their phone while cycling. During the experiment, only one participant decided to wear the helmet that was offered.

3.2 Performance measures

3.2.1 Speed

The GPS watch failed to register data for one participant, therefore the speed results are based on N=23. Based on the GLM procedure, there was a main effect of condition type on speed (Hotelling's $T = 7.60$, $p < 0.001$). Specifically, when compared with the control conditions (C1 and C2) the participants cycled slower in all of the other conditions (see Figure 2 and Table 2). However, no significant difference in cycling speed was found when texting with the touch screen phone was compared with texting with the conventional phone. No significant effect of any of the conditions on the standard deviation of cycling speed was found (SD Speed: Hotelling's $T = 0.49$, NS).

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Insert Figure 2 about here
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3.2.2. Lane position

Lane position is displayed per condition in Figure 3. As mentioned previously, the cycle lane was divided into 9 strips, each 0.213 m wide (see Figure 1). The position of the front wheel was scored twice per second. Texting affected lateral position, which shifted towards the centre of the lane. This effect was largest when operating the touch screen phone and was significantly different ($p = .042$) from the condition in which the conventional phone was operated. No effect on mean position as a result of telephoning (handheld) was found. See Table 2 for all the results of the statistical tests.

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Insert Figure 3 and 4 about here
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Variation in lateral position is shown in figure 4. Compared with cycling with one hand on the handlebars, the increase in swerving in the condition where participants sent a text message was not statistically significant. In addition, no significant difference in variation in lateral position between cycling with one or two hands on the handlebar was found (C1 versus C2). However, when compared with condition C2, the increase in lateral position variability in the conditions where participants sent text messages was significant ($p < .05$), indicating that cycling with one hand *plus* operating a device did deteriorate lateral control even when just cycling straight along a cycle path.

3.2.3. Reaction and brake time

A large effect on reaction and brake time was found as a result of listening to music with in-ear headphones. Specifically, the auditory stop signal was only heard by four participants, meaning that 20 out of 24 participants completely missed the auditory signal in the music condition. For the rest of the conditions no effects on reaction time to the auditory stop signal were found with the exception of the comparison between handheld telephoning (RT=3.2 s) versus cycling with a companion or cycling with two hands on the handlebars (both RTs=2.4 s).

3.2.4 Visual peripheral detection

Most of the roadside objects were detected if participants were just cycling without a secondary telephone task, in particular when cycling with one hand (see Figure 5 and Table 2). Conversely, the performance in all of the telephone conditions, and in the cycling companion condition, was worse compared to when just cycling (C1 and C2). Also, in the touch screen phone condition significantly fewer objects were detected compared with the performance in the conventional phone condition.

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Insert Figure 5 about here
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3.3 Self reports

3.3.1 Self-reported effort

Compared with cycling with one or two hands on the handlebar, all additional conditions significantly increased self-reported effort (Figure 6, Table 2) from 10 ("almost no effort") up to 40 ("some effort") – 65 (between "rather much" and "considerable effort"). Texting with a touch screen phone was not experienced as being significantly more effortful than using a conventional phone.

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Insert Figure 6 about here
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3.3.2 Self-reported risk

With regard to experienced risk, again all contrasts with the control conditions (Table 2) differed significantly (see Figure 7). Also, more risk was reported in the control condition when riding with one hand compared with two, and when operating either a touch or conventional mobile phone.

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Insert Figure 7 about here
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Insert Table 2 about here
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4. Discussion and conclusions

In the present study the effects of texting (with and without listening to music), talking on, or playing a game with a touch screen phone on bicycling behaviour were compared with effects of using a conventional mobile phone to text, the common situation of cycling and conversing with a companion cyclist, and with just cycling without a secondary task. It was found that all the secondary phone tasks affected performance, in particular cycle speed was reduced, and fewer stimuli in the periphery were detected. This coincided with higher ratings of risk and mental effort, reflecting that a lower speed did not compensate for all of the negative effects.

Compared with the effect of sending a text message from a conventional phone, it was found that texting with a touch screen smartphone affected position in the cycle lane. Specifically, the participants tended to keep a cycling position with more distance from the kerb when texting with the touch screen. Also fewer objects in the periphery were detected when entering text on a touch screen telephone. It should be noted however that these objects were unexpected. Also, the relevance for cycling of detecting these objects can be questioned, as they were not necessarily relevant to the cycling task and therefore did not require a behavioural change or increased alertness. Nevertheless, the results do seem to reflect that the spare capacity for detecting objects in the periphery while cycling was reduced by the secondary tasks.

Texting with a touch screen was not subjectively experienced as more effortful or risky than with a conventional phone, nor did it lead to slower cycling than texting with a conventional phone. Therefore, given the earlier mentioned performance effects related to using a touch screen phone this may be a risk to safety as participants may be unaware of the extra changes in performance they are experiencing when using a touch screen.

On the basis of the results of this study it is therefore concluded that using a touch screen to text can deteriorate cycling behaviour more so than conventional phones when sending a text message, although it is also clear that using a conventional phone to text impacts on cycling performance. Playing a game on a touch screen mobile phone was also found to deteriorate cycling behaviour. Important in this respect is the increase in swerving found for the texting and gaming conditions, as more variation in lateral position increases the chance to collide with the kerb or with other traffic participants. Also the fact that cyclists rode in a more central position within the cycle lane in conditions where they were texting and gaming may be a threat to safety depending on the type of road a cyclist is riding on. It is therefore noteworthy that texting on a smartphone leads to the most central position, significantly different from the position chosen when texting on a conventional phone. In the city centre, cyclists often share the road with cars as there is no separate cycle path. In those conditions a position further away from the kerb could lead to conflicts with these cars, even in the Netherlands where compared to many other countries drivers are more aware of bicycles but still expect cyclists to keep to the right. A study by Walker (2007) also showed that the further a rider was riding away from the edge line on the road or pavement, the closer vehicles pass the cyclist. Large vehicles in particular may endanger safety. However, the present study was performed on a single-direction separate cycle path, and not on a road that is shared with motorised vehicles. As such, a position further away from the curb on a single direction cycle path may mainly reflect positive behavioural adaptation, or an increase in safety margins. Future studies, e.g. an observational study, may shed light on the issue whether these effects also occur on other types of roads.

Apart from observing behaviour in naturalistic conditions, future studies could also focus on more critical situations, such as negotiating curves or intersections. It may be that cyclists regulate workload and delay operation of phones in such critical situations.

Very little is known about gaming while cycling (or while driving a car). This condition was included because it has been mentioned in the Dutch media to be a problem with young children in traffic. However, the effects of gaming in this study were not as large as may have been expected and none of the participants had experience with playing games while cycling. This limited effect of gaming may be related to the game that was played. With the slow speed version of the game Snake II, there is ample time to look at the road before the touch screen had to be touched to change the snake's direction. Playing it at a more demanding thus higher speed or using another game that demands more immediate attention from players may have posed a larger load on the cyclist's attention and may have a larger impact on cycle control. Although, whether cyclists do naturalistically play such highly demanding games, rather than low workload games, while cycling would also have to be investigated. The present results however do show that playing a game such as Snake II while cycling has similar negative effects on cycling behaviour as talking on a mobile phone.

Although the main focus of the present study was on effects of operating a touch screen mobile phone opposed to a conventional keypad mobile phone, other common activities while cycling were also included, such as making a telephone call. The task used in the study to look at the effects of having a conversation on a mobile phone was, compared to previous studies (De Waard et al., 2010, 2011), made slightly more realistic. In the earlier studies a subtraction (mathematical) task was used, whereas here it was changed into a dialogue with the word-game verbal task. The dialogue was perhaps still artificial but at least the connecting task also required active thinking. The effects of performing this dialogue task while talking on a phone were compared with a condition with the same task where one of the experimenters cycled next to the participant, a common way of cycling in the Netherlands. This condition could also be compared to talking with a passenger in a car (Caird et al., 2008, Collet et al., 2010). In the present study there was a significant difference in the response to the auditory stop signal which was almost one second higher for the handheld telephoning condition than for the cycling with a companion condition, although cycling with a companion did not significantly impact on reaction time when compared to simply cycling alone. Bellinger et al. (2009) found an increase in reaction time to visual stimuli as a result of handling a mobile phone while driving; however, it is interesting to see that in the present study there is not only an effect on visual performance but also a reduced response to auditory stimuli.

In the telephone condition more objects were missed in the cycling companion condition than in the handheld telephone condition or when cycling alone. The missing of objects could therefore be taken as a reduction in situation awareness while cycling with a companion and may be related to the reported higher number of accidents when cycling with a companion or passenger (Ormel et al., 2009), although whether there is a direct relation between cycling with a companion and accident involvement needs to be confirmed by further research.

Finally, as with the earlier De Waard et al., (2011) study, the major risk of the use of in-ear headphones while cycling was shown with the auditory stop signal only being heard by four out of 24 participants in this condition. Although, it should be noted that while the decibel level of the horn was constant participants were allowed to individually select the volume at which they listened to the music. However, given that the instruction was to listen to the music at a preferred level this likely reflects the volume they would use while cycling under real world conditions, or perhaps even lower given that the participants were aware that they had to perform the auditory stop task. This means that auditory signals in traffic will likely be missed by cyclists using in-ear headphones to listen to music. Since cyclists make more use of auditory signals than car drivers, e.g. to detect cars approaching, the use of in-ear headphones in traffic should be discouraged.

Different types of distraction were evaluated in this experiment, talking on a phone or with a cycle companion, texting on a conventional and touch screen smartphone, texting and listening to music, and playing a game on a touch screen smartphone. It can be concluded that all these secondary tasks, many of which can be observed to be commonly performed while cycling in traffic in the Netherlands, have an effect on behaviour. In general, the performance of these tasks leads to an increase in safety margins in terms of decreased cycle speed and increased distance to the curb. The latter is also required because of increased swerving. Some secondary tasks have a larger effect than others, in particular the operation of a touch screen increases distance to the curb and reduces cycle speed the most. With smartphones establishing a dominant position on the mobile phone market the traffic safety of cyclists operating these phones while cycling may be at risk. Observation of actual behaviour in the real world may give an indication how widespread this threat to traffic safety is.

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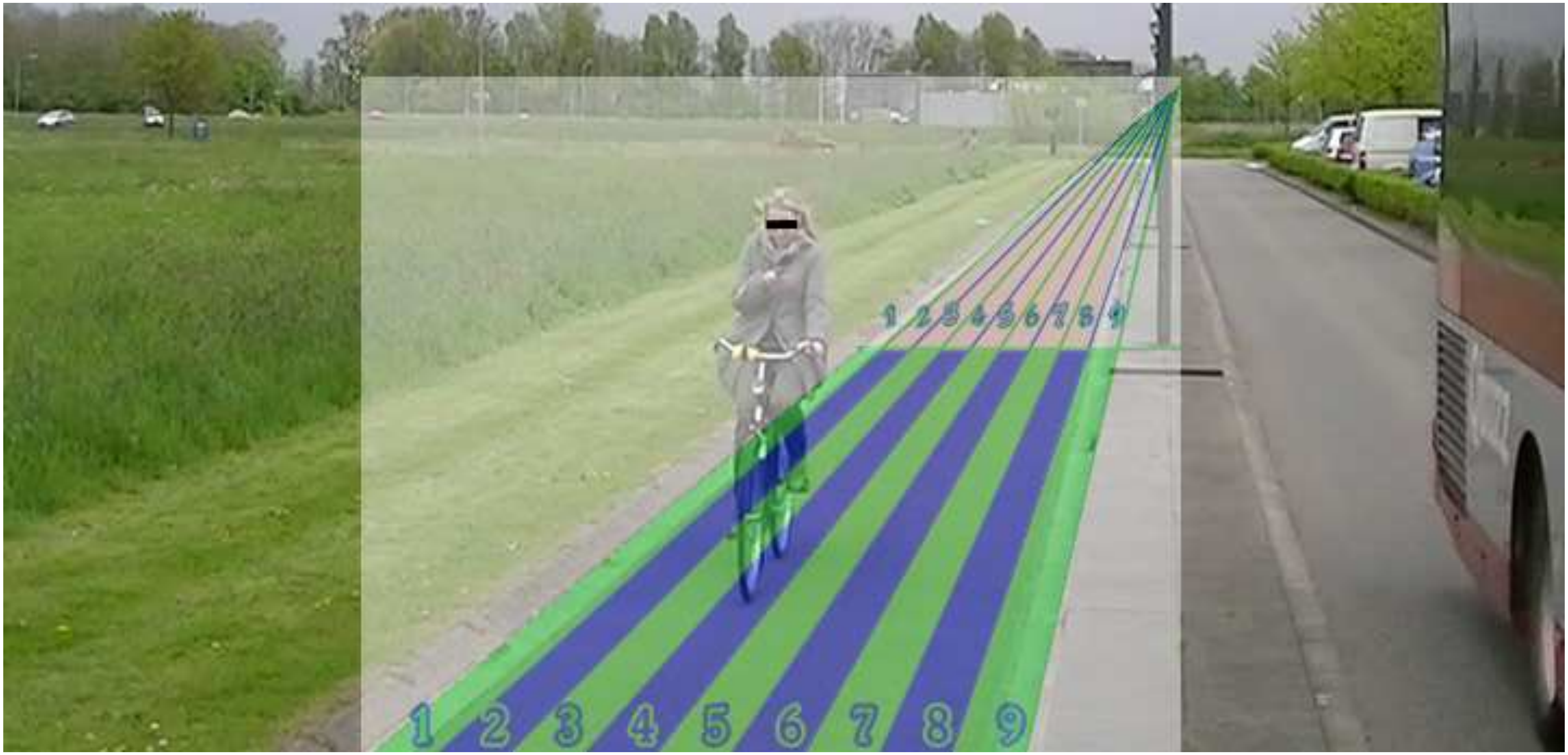

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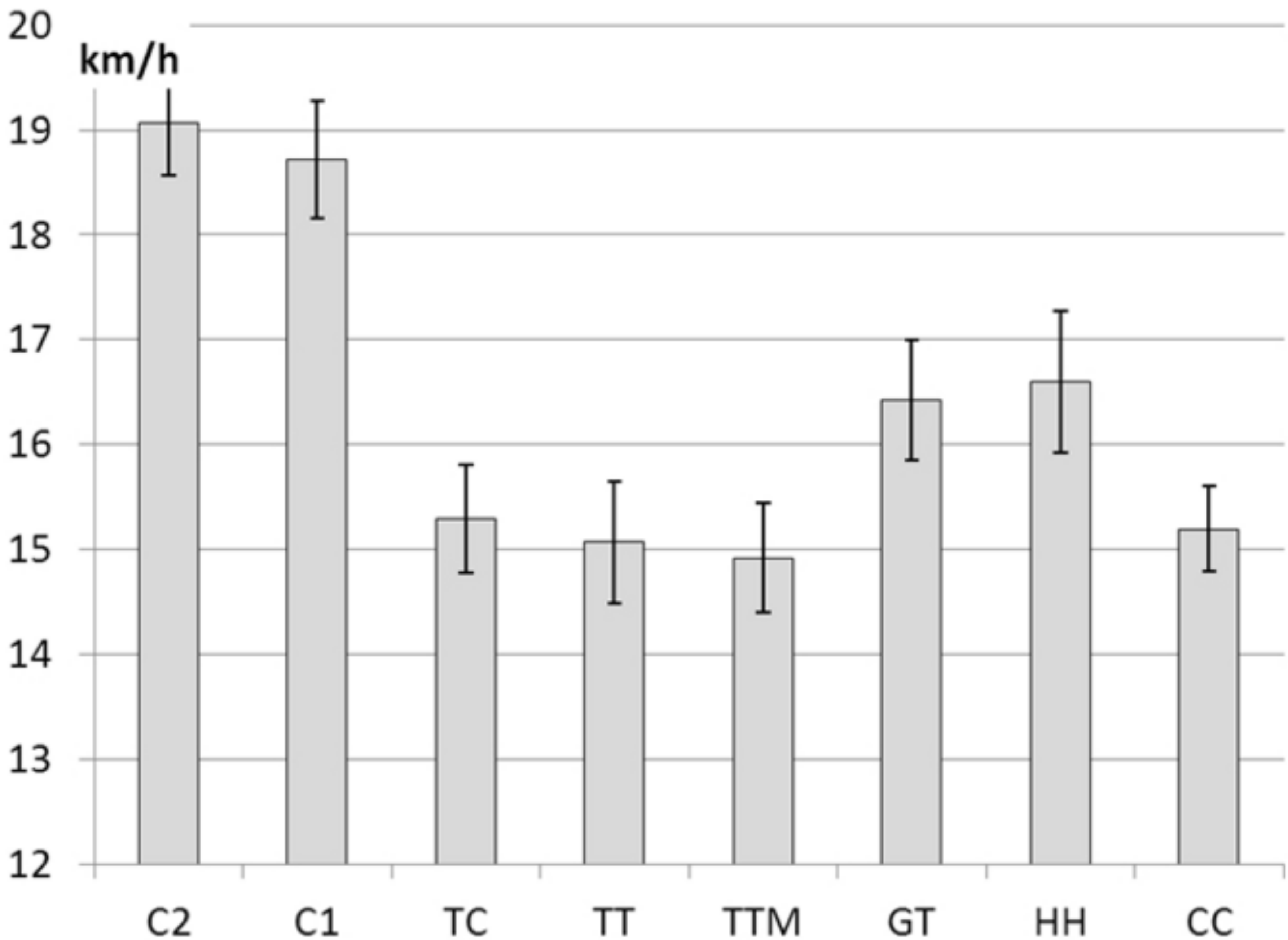

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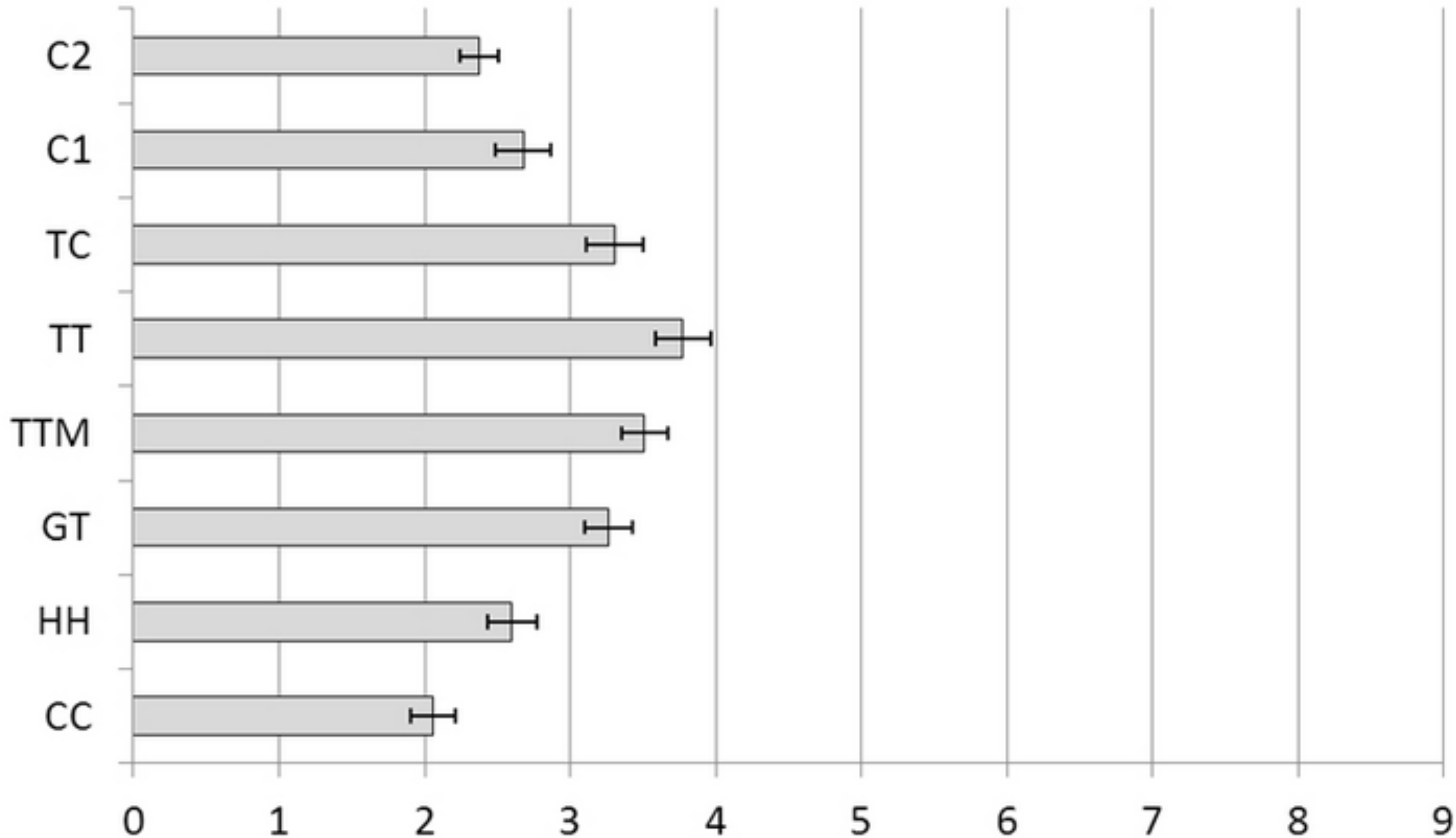

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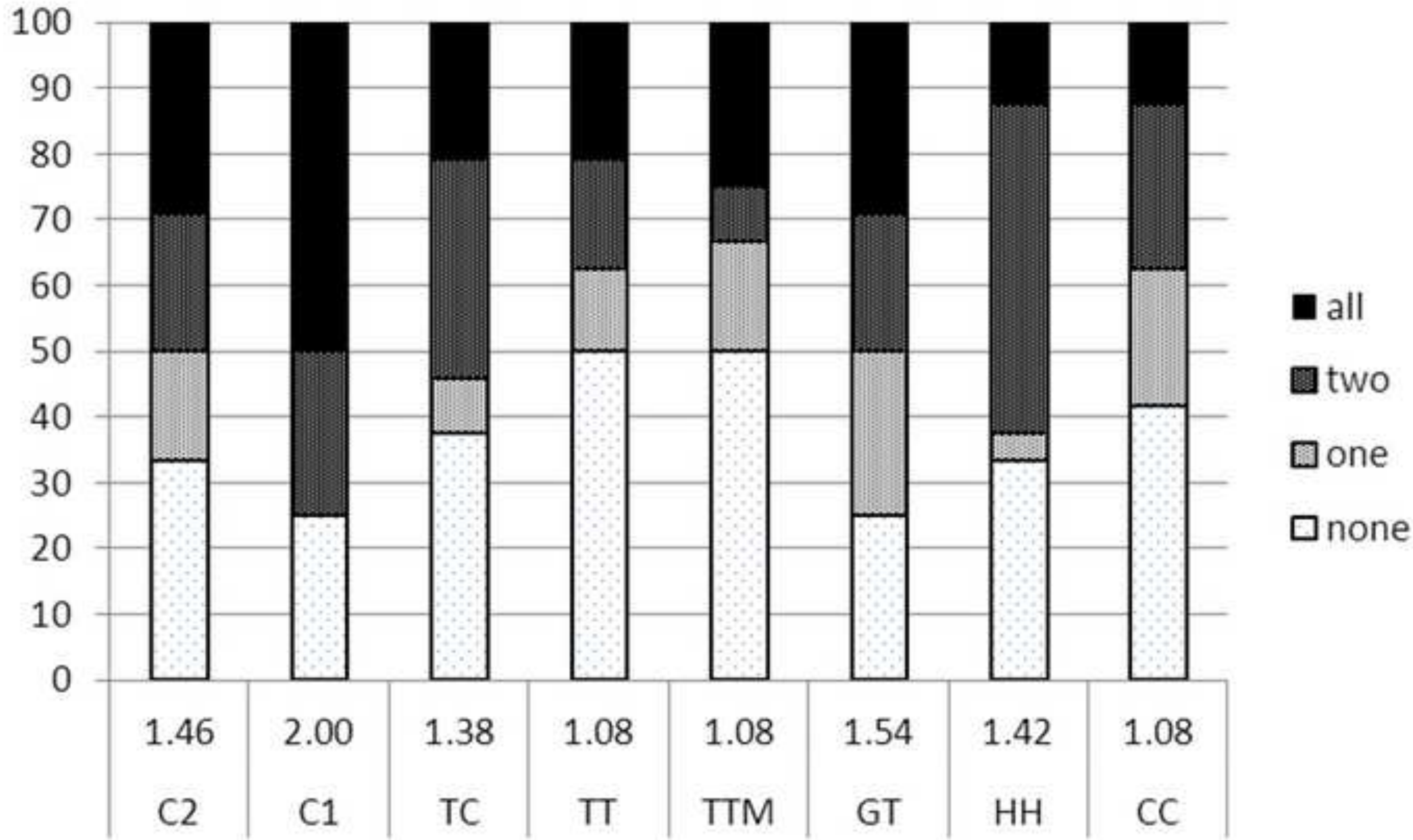

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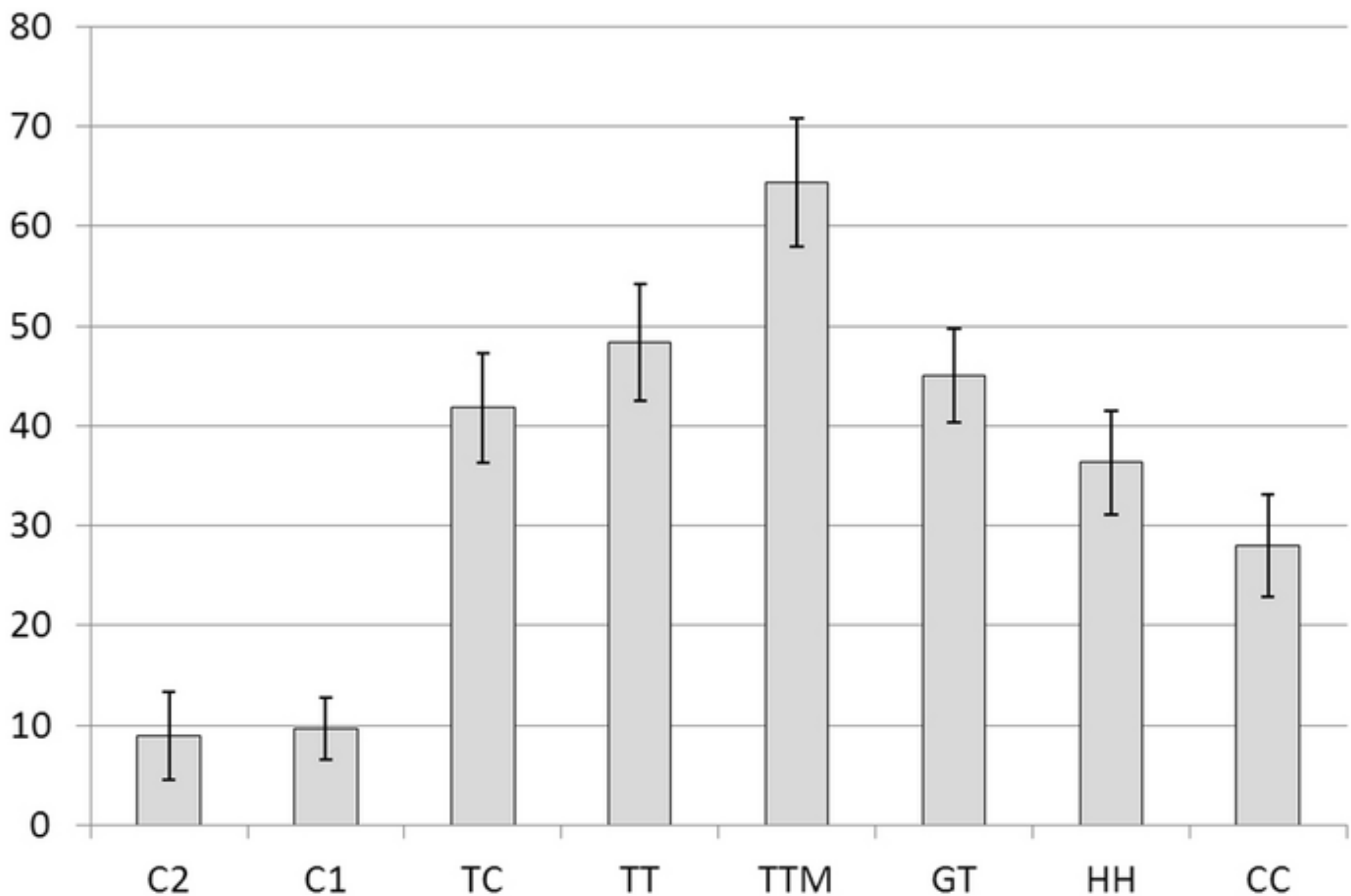

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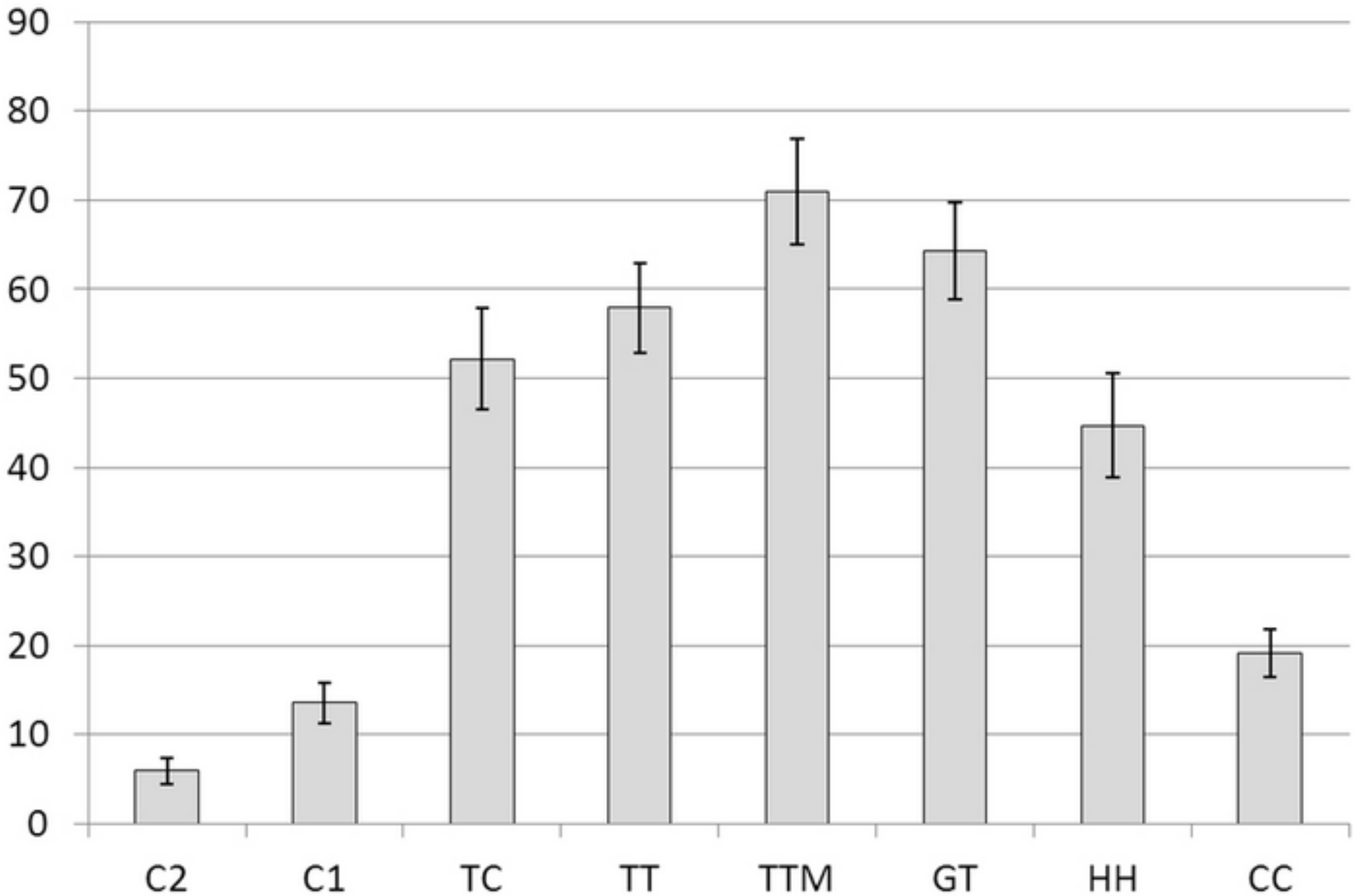

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