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To cite this article: Peter Le, Jaejin Hwang, Sarah Grawe, Jing Li, Alison Snyder, Christina Lee & William S. Marras (2015) Biomechanical patterns of text-message distraction, *Ergonomics*, 58:10, 1690-1700, DOI: [10.1080/00140139.2015.1030459](https://doi.org/10.1080/00140139.2015.1030459)

To link to this article: <http://dx.doi.org/10.1080/00140139.2015.1030459>



Accepted author version posted online: 13 Apr 2015.  
Published online: 24 Apr 2015.



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## Biomechanical patterns of text-message distraction

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*(Received 7 April 2014; accepted 11 March 2015)*

The objective of this study was to identify biomechanical measures that can distinguish texting distraction in a laboratory-simulated driving environment. The goal would be to use this information to provide an intervention for risky driving behaviour. Sixteen subjects participated in this study. Three independent variables were tested: task (texting, visual targeting, weighted and non-weighted movements), task direction (front and side) and task distance (close and far). Dependent variables consisted of biomechanical moments, head displacement and the length of time to complete each task. Results revealed that the time to complete each task was higher for texting compared to other tasks. Peak moments during texting were only distinguishable from visual targeting. Peak head displacement and cumulative biomechanical exposure measures indicated that texting can be distinguished from other tasks. Therefore, it may be useful to take into account both temporal and biomechanical measures when considering warning systems to detect texting distraction.

**Practitioner Summary:** Text-message distraction while driving has been associated with an alarming and growing number of injuries and fatalities. This study identified potential biomechanical indications that could potentially serve as a warning with the intent of reducing crashes from texting.

**Keywords:** texting; text-messaging; cell phone distraction; mobile phone distraction

### 1. Introduction

Police reports in the USA from 2008 have collectively reported about 515,000 injuries and 5870 fatalities due to distracted driving (Center for Injury Research and Policy 2013). Between 1999 and 2008, a report from Wilson and Stimpson (2010) estimated that over 50,000 fatalities were due to distracted driving. Of these fatalities, many were suspected to be due to texting while driving. In recent years, there has been a drastic increase in mobile phone ownership and usage. Moreover, depending on the context of the conversation, it has been reported that people tend to favour texting over talking on their mobile phones (Reid and Reid 2007). The problem with texting is that it poses a danger due to the amount of cognitive resources required for attention when compared to other common tasks during driving (Liang and Lee 2010). Aside from the risk imposed from cell phone usage while driving (Fitch et al. 2013), texting has been found to increase accident risk by about 23.2 times compared to not texting (Hanowski 2011). A study by Sanbonmatsu et al. (2013) has shown that people are incapable of multitasking efficiently. When attempting to multitask texting and driving, resources are appropriated to the task that requires higher cognition. The result is reduced awareness of the surroundings and inattention blindness in which drivers fail to recognise objects in their line of sight. During texting, the eyes shift away from the road, thus obscuring peripheral vision. Reduced awareness of a driver's surroundings has been shown to lead to lateral lane deviations, missed signs, slower driving, and in many cases, accidents (Drews et al. 2009; Hosking, Young, and Regan 2009; Owens, McLaughlin, and Sudweeks 2011). With an increase in accidents due to texting while driving, the authors suspected that this dangerous trend may continue to rise unless measures are put into place to mitigate them.

Given the magnitude of the problem, the first approach towards mitigating the problem is to identify when drivers are distracted. Previous studies have evaluated many different approaches to track distracted driving. Measures have included electroencephalography (Mouloua et al. 2012), eye tracking (saccades and blinking) (Hosking, Young, and Regan 2009; Liang and Lee 2010), head tracking (Dong et al. 2011) and driving performance (Libby and Chaparro 2009; Strayer et al. 2001; Young, Salmon, and Cornelissen 2013). Although these studies shed a valuable light on physiological causal pathways of distracted driving, they may not be practical to implement in a driving environment due to instrumentation and environment requirements. Thus, a void exists in which we do not have a practical measure to identify when distracted driving is occurring. Biomechanical measures may be better suited for practical use.

Biomechanical measures such as kinematic, moment and force tracking have long been used in studies such as lifting, pushing and pulling (Hoozemans et al. 2004; Knapik and Marras 2009; Marras and Granata 1997). Torso motions can be

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precisely tracked by changes in moment and kinematic measures. During distraction, particularly during texting, the eyes are focused upon the cell phone. Relative to the task at hand, the head tends to work synchronously with the eyes (Land 2004; Pelz, Hayhoe, and Loeber 2001). As the head shifts, the centre of mass would also shift. Therefore, it is postulated that if torso changes are associated with moment arm changes, then the same association may also apply to head motion.

The difficulty in distinguishing when a driver is texting is due to kinematic similarities that may appear between texting and other common tasks. These include but are not limited to eating/drinking, adjusting controls, seat deviations, general gazes to evaluate surroundings or shifting gears. However, the amount of time spent on each task tends to be different. Time in conjunction with biomechanical measures produces a measurement of cumulative biomechanical exposure to the distraction task. Understanding how these variables work together may assist in distinguishing texting-related distraction compared to other common tasks that may not be as risky. Currently, the biomechanical mechanism for separating texting distraction from other distractions and driving tasks is neither clearly defined nor well understood.

It was hypothesised that one could identify biomechanical measures in conjunction with temporal conditions that may be able to distinguish texting from other common tasks. Therefore, the objective of this study was to explore possible biomechanical measures that may uniquely identify texting from other common tasks within a static, simulated automotive seating environment. These measures may ultimately provide the basis for warning a driver when the distraction poses a danger.

## 2. Methods

### 2.1. Approach

The purpose of this study was to explore and identify biomechanical measures that may differentiate texting from other common tasks in a static, automotive seating environment. Biomechanical measures of moment, head displacement, time and cumulative biomechanical exposure were evaluated for various tasks typically observed during driving, including texting.

### 2.2. Experimental design

A  $4 \times 2 \times 2$  completely randomised and repeated measures design was used to minimise carry-over effects. Each condition was completed twice for a total of 32 trials per subject.

#### 2.1.1. Independent variables

Main effects of task type, task direction and task distance were evaluated. The task included four levels: texting, visual targeting, weighted movements and non-weighted movements. In the context of this experiment, weighted movements involved picking up a beverage, whereas non-weighted movements involved motions for adjusting controls. Visual targeting tasks were operationally defined as tasks that required positioning the head in order to observe the target directly in the line of sight. Direction included two levels: front (sagittal plane) and side (approximately  $45^\circ$  to the right of the sagittal plane). Distance included two levels: close and far (task executed with forearm as close as possible to the body and 75% of arm length, respectively). The tasks were chosen from pilot testing and based upon their common representation during driving (Olson et al. 2009), as well as the directions and distances in which they typically occur. Both direction and distance were chosen because of their effects on the measured moment arm. Task descriptions relative to their main effects are shown in Table 1.

#### 2.1.2. Dependent variables

Continuous, biomechanical measures of moment, head displacement, length of task execution time and cumulative biomechanical exposure were evaluated.

### 2.3. Subjects

Sixteen subjects (6 males and 10 females) representative of the texting population were recruited from the local university population for the study. The age representation was gathered from Tison, Chaudhary, and Cosgrove (2011) stating that the majority of the texting population was between 21 and 34 years old, with the riskiest population under the age of 25. In our study, ages ranged from 20 to 29 years, with an average age of 23 years. Anthropometric data for height, weight and arm length were collected from the participants (Table 2).

Table 1. Descriptions of the tasks relative to their main effects.

Direction	Distance	Task			
		Text-messaging	Visual targeting	Weighted movement	Non-weighted movement
Front	Close	Phone directly in front, close to body, near abdomen	Stretch neck forward as if trying to focus on odometer reading	Pick up bottle from location between legs closest to body	Use movement necessary to adjust sunglasses
Front	Far	Phone directly in front, near steering wheel	Look over the steering wheel to check for traffic around bends	Pick up bottle from between legs from location near steering wheel	Use the turn signal
Side	Close	45° to the side, phone near abdomen	Glance at the side mirror	Pick up bottle from location 45° to the side, and close to thigh	Adjust a simulated control in the centre console closest to thigh
Side	Far	45° to the side, phone at 75% of arm length	Turn body to check blind spot	Pick up bottle from location 45° to the side, and at 75% of arm length	Adjust the volume on the simulated radio

Table 2. Subject anthropometry (mean  $\pm$  standard deviation).

	Overall	Male	Female
Age	23.8 $\pm$ 2.6	24.3 $\pm$ 3.3	23.3 $\pm$ 2.0
Height (cm)	168.4 $\pm$ 9.5	175.8 $\pm$ 6.5	163.1 $\pm$ 7.6
Weight (kg)	64.9 $\pm$ 10.2	74.0 $\pm$ 8.5	58.4 $\pm$ 5.0
Arm length (cm)	80.8 $\pm$ 5.5	84.5 $\pm$ 6.0	77.6 $\pm$ 2.4

## 2.4. Procedure

Consent from the university's institutional review board was obtained from each participant. Anthropometric data were collected and used to adjust the mock-up vehicle seat and the target direction for side tasks (45° from sagittal plane) as well as the target distances (far tasks at 75% of arm length). Participants were advised of the task descriptions for each condition, which were assigned randomly. A total of 16 conditions were repeated twice for a total of 32 trials. During each trial, a measurement was collected (at least 5 s) in a neutral driving position (hands at '10 and 2 o'clock' on the steering wheel) as a baseline to the biomechanical changes of each task. As the subject commenced a task, the researcher pressed a Schmitt trigger to initiate a pulse within the data acquisition system to denote the beginning of the distraction period. The trigger was pressed again once the subject completed the task and returned her hands to the baseline neutral position.

During text-messaging tasks, two controls were put into place to mitigate confounding factors. Subjects used their own phones (12 subjects with touchscreens, two with a QWERTY setup and one with a tactile key pad) to reduce the effects of learning to text on other phones and only one hand was used to text. Texting was operationally defined in this study as the reception, reading and response to a message. Random texts consisted of 7–10 words sent to the subjects' phone from the researcher. Subjects were asked to respond by rewriting the text received. Text messages used for this study were gathered from Crisler et al. (2008) and Owens, McLaughlin, and Sudweeks (2011). Each texting trial began with the phone at located at a distance of 75% of arm length to the right side of the subject. At the reception of the text (denoted by a tone from the phone), the subject would pick up the phone and bring it to the position specified for the condition (close/front, far/front, close/side, far/side) and commence reading and replying to the text. The subject would return the phone back its original position upon completion of the task, which would also denote the end of the trial.

Tasks involving visual targeting were dependent on the distance/direction assigned. The combination of the front and close condition required the subject to move their head forward as far as they can with minimal forward movement of the chest. This motion was used to simulate if someone were trying to adjust their focus on a particular item right in front of their vehicle under low-visibility driving. The front and far condition required the subject to look over the steering wheel to simulate checking blind spots on turns ahead. This required the subject to remove contact with the seat back and move closer to the steering wheel. The side and close condition required the subject to glance at the right-side mirror. The side and far condition required the subject to turn their torso approximately 45° to the right as if they were checking their blind spot.

Weighted movements involved picking up a bottled beverage and taking a drink, then placing it back in its original position. The initial placement of the bottle was dependent on the condition assigned. Front and close required the subject to pick up the bottle at a location between the legs as close to the body as possible. Front and far involved a location between the legs, but closer to the steering wheel (75% of arm length). Side and close required the subject to pick up the bottle from a simulated cup holder that was close to the body, but 45° to the right, whereas side and far was in the same direction, but 75% of arm length.

Non-weighted movements were movements that involved small adjustment of controls or small grooming tasks. Front and close involved the minor adjustment of sunglasses or a simple grooming task (i.e. pressing them back up on the nose). Front and far involved use of the turn signal. Side and close involved simulated pressing of a button on the centre console (i.e. seat warmer). Side and far involved simulated adjustment of the radio volume.

For all the tasks in which texting was not involved (visual targeting, weighted movement and non-weighted movement), the researcher directed the subject as to when to initiate the task.

## 2.5. Apparatus

### 2.5.1. Mock-up vehicle seat and setup

The mock-up vehicle seat consisted of foam car seat, steering wheel and wooden foot pedals set up in a left-hand drive configuration. The experimental setup used for this study can be seen in Figure 1 and was a result of pilot studies and subject comfort. The seat was the same for all subjects and could not be adjusted. The steering wheel was set at about chest level and 75% of arm length for the distance. For tasks requiring weighted movements, simulated cup holders were placed at 75% of arm length, 45° from the sagittal plane (weighted/far/side condition) and at 45° from the sagittal plane closest to the thigh (weighted/close/side condition).

### 2.5.2. Biomechanical data

A force plate (Bertec 4060A; Bertec, Worthington, OH, USA) was placed under the mock-up vehicle seat to measure the global moment. The OptiTrack optical motion capture system (NaturalPoint, Corvallis, OR, USA) with 24 infrared cameras were used. Three reflective markers were attached to a hat worn by each participant to track the head displacement for each task. Displacement was calculated relative to a baseline before the initiation of each task.

## 2.6. Data analysis

Continuous, moment data collected during each condition were rectified and peaks were extracted for moments in the sagittal ( $M_x$ ), lateral ( $M_y$ ) and axial ( $M_z$ ) planes relative to baseline. Peak head displacement data were extracted in the x-, y- and z-directions. The length of time from the initiation to the completion of the task was also analysed for each condition. Furthermore, the cumulative biomechanical exposure to distraction was represented by the area under the curve for each condition.

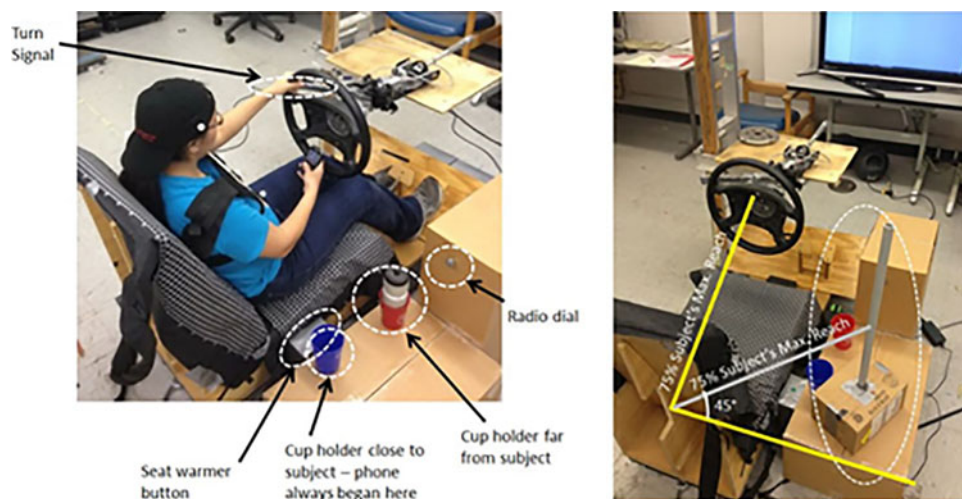


Figure 1. Mock-vehicle experimental setup. The post in the second figure was utilised as a target for the side/far tasks.



## 2.7. Statistical analysis

General linear models (JMP 10.0, SAS Institute, Cary, NC, USA) were used to evaluate the dependent variables for the main effects of task, direction, distance and their two-way and three-way interactions at  $\alpha = 0.05$ . Post hoc Tukey tests were used to check for significant differences among tasks.

## 3. Results

Statistically significant differences for each of the biomechanical measures relative to the independent variables and their interactions are summarised in Table 3. Examples of the biomechanical signatures in which the basis of the results were derived can be found in Figure 2. The square wave signal describes the initiation and termination of each task. Moments and kinematics were analysed between the onset and offset of the trigger signal.

### 3.1. Temporal differences between tasks

The average amount of time to accomplish each task is shown in Figure 3(a). Texting took the longest amount of time followed by the weighted task (obtaining and drinking a beverage), and then non-weighted and visual tasks.

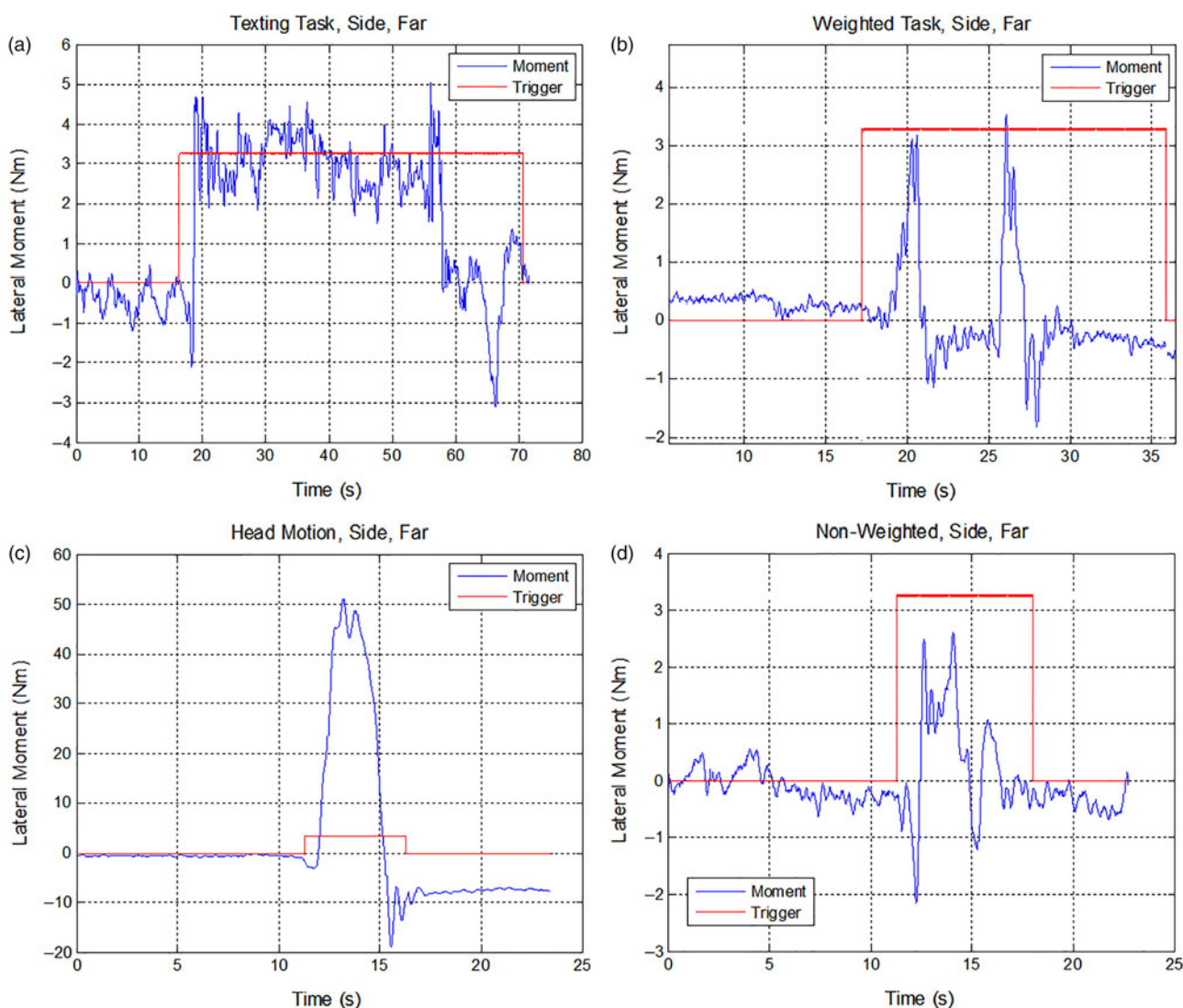


Figure 2. Examples of the biomechanical signatures of tasks to the right side and far away from the torso. The data represented are the lateral moment (Nm). The square wave denotes the beginning and end of each task via Schmitt trigger. (A) Text-messaging, (B) obtaining a beverage and drinking, (C) checking blind spot from the side (D) adjusting the radio.

Table 3. Summary of the statistically significant effects and interactions for the dependent measures.

Dependent variables	Task	Direction	Distance	Direction × distance	Task × direction	Task × distance	Task × direction × distance
Time	***	*					
Peak moment (Nm)							
Sagittal $-M_x$	***	*	***		**	***	
Lateral $-M_y$	***	***	***	***	***	***	***
Axial $-M_z$	***	***	***	*	*	***	***
Cumulative moment exposure (Nm s)							
Sagittal $-M_x$	***	***	***	*	**	***	**
Lateral $-M_y$	***	***	*	***	***	*	***
Axial $-M_z$	***		*			*	
Peak head motion (mm)							
X-direction (anterior +)	***						
Y-direction (lateral right +)	***						
Z-direction (inferior +)	***						

Note: \* < 0.05, \*\* < 0.01, \*\*\* < 0.001.

### 3.2. Peak head displacement

Peak head displacement from baseline in all directions ( $x$ ,  $y$  and  $z$ ) is shown in Figure 3(b)–(d). Texting was statistically distinguishable from other tasks. Displacement in the  $x$ -direction refers to anterior/posterior motion (anterior positive),  $y$ -direction refers to lateral motion (right-side positive) and  $z$ -direction refers to superior/inferior motion (inferior positive). Only peak displacements in the positive directions showed statistically significant differences.

### 3.3. Peak moments

Two-way interactions of task/direction and task/distance were assessed for the peak sagittal ( $M_x$ , anterior positive), peak lateral ( $M_y$ , right lateral positive) and peak axial moments ( $M_z$ , clockwise positive). Results for the sagittal and lateral planes are displayed in Figure 4. The axial plane results were omitted because of their lack of biological plausibility in observance of the raw signal. In the sagittal plane, visual tasks were distinguishable from weighted, non-weighted and texting tasks for the task/direction interaction. The visual task was only distinguishable from other tasks when the task was far from the body. At this level of analysis, texting was not clearly distinguishable from weighted and non-weighted tasks in any plane.

### 3.4. Cumulative moment exposures

Three-way interaction effects for the cumulative moment exposure (CME) are displayed in Figure 5. CME is operationally defined as a measure of the moment over time during the task. Texting was distinguishable in the sagittal plane only when it occurred close and to the front, close and to the side, and far and to the side. In the lateral plane, texting was distinguishable from other tasks when executed on the side (far and close).

## 4. Discussion

Our study demonstrated that biomechanical measures of CME and peak head displacement were able to distinguish texting relative to other common tasks within a static, simulated automotive environment. Peak moment measures were not able to distinguish texting from drinking (weighted tasks) and adjustment of controls (non-weighted tasks). Since the peak is a discrete point in time, texting signals tended to look similar to other distractions/movements because of the trajectory of the upper extremities to reach for the objects. These reaching movements are usually linked to a distraction-related event (Klauer et al. 2006). However, texting requires higher cognitive processing (Klauer et al. 2006). It involves reallocation of cognitive resources from visual, tactile and cognitive resources, away from driving, thereby resulting in increased accident risk (Liang and Lee 2010).

During texting, the cell phone is typically stabilised for visual focus. As the eyes transfer to the location of the phone, it was postulated that the head tends to follow. This inference is supported by Rempel et al. (2007) as they found that in order to enhance visual acuity, the head moves closer to the visual display to accommodate the eyes. Our study found that texting was distinguishable from the peak displacement of the head. The displacements were highest in the anterior, inferior and

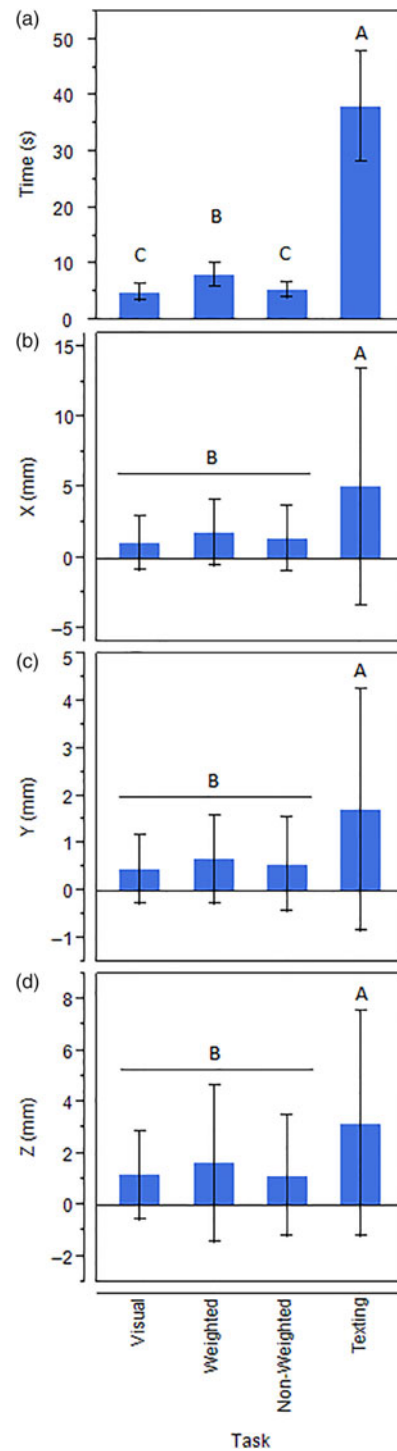


Figure 3. (A) Average time to execute each task and peak head displacement for each task type in the (B) *x*-direction (anterior positive), (C) *y*-direction (right lateral positive) and (D) *z*-direction (inferior positive) (mean  $\pm$  standard deviation).

right lateral directions which were associated with looking down and looking to the side. Although useful, there may be a higher probability of false positives if detection were based upon the peak displacement alone. To enhance specificity, it was postulated that a temporal factor would be needed to understand the dynamics of the head movement. Unfortunately, when incorporating the temporal factor to the displacement of the head, no statistically significant differences were found. Therefore, another route was investigated, the biomechanical moment arm. During pilot testing, it was observed that



movement of the arms, head or combination thereof produced a change in the moment. In order to complete the task of reading and texting, the phone was usually kept still, thereby lengthening the exposure to the moment. A study from Huxhold et al. (2006) supports this suggestion showing that tasks requiring visual and cognitive focus resulted in less motion, particularly in younger people. Texting also requires much more time and focus than general gazes, drinking and eating, or minor adjustment of controls.

In our study, short-message texting (reception, reading and response) took about  $38.1 \pm 9.83$  s, which was significantly longer than the second longest task, obtaining and drinking a beverage ( $8.0 \pm 2.1$  s). A finding from Drews et al. (2009) indicated an average time of  $57 \pm 21$  s for texting. As a stand-alone measure, time does not provide any information on the mechanics of the task. However, when taken into consideration with the moment, it may be possible that the initiation of the task may be seen through the shift in the moment relative to baseline (CME). The idea behind this measure was that area under the curve may be collected on a continuous basis until it passes a threshold signifying distracted behaviour. The three-

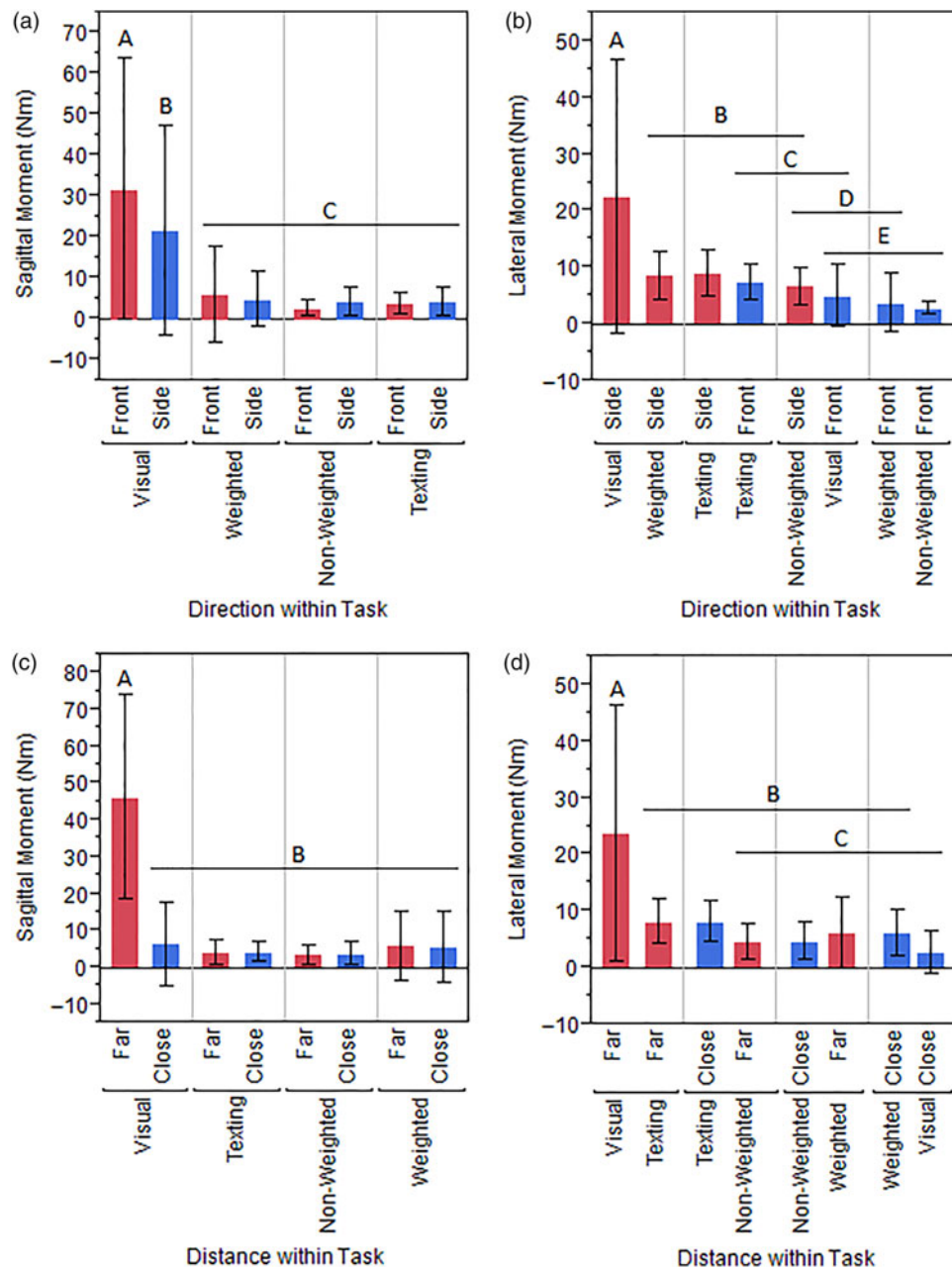


Figure 4. Peak moments for the two-way interactions of task type and direction in the (A) sagittal and (B) lateral planes and task type and distance in the (C) sagittal and (D) lateral planes with post hoc results (mean  $\pm$  standard deviation).

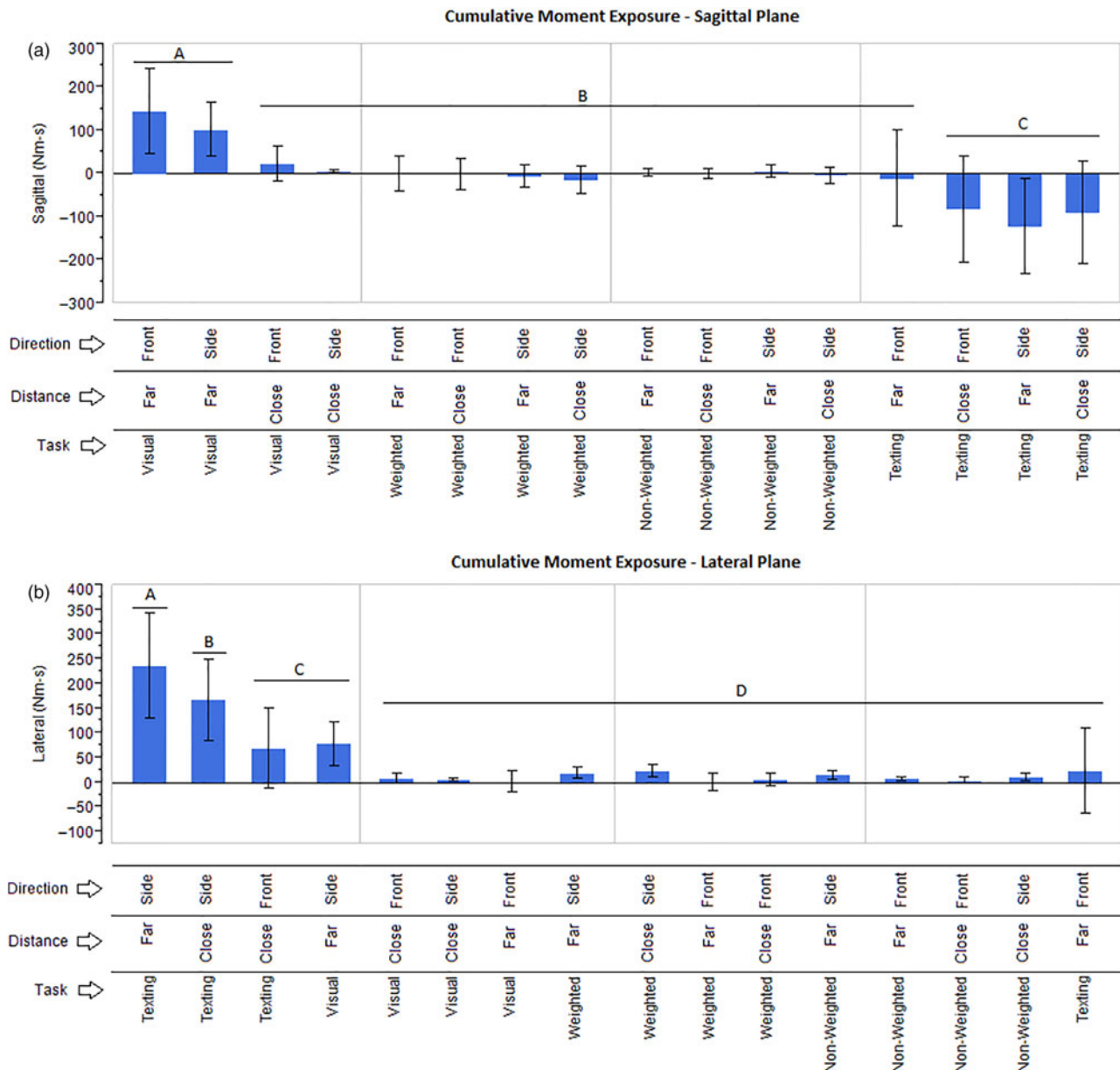


Figure 5. Cumulative biomechanical exposures in the (A) sagittal and (B) lateral planes for the three-way interaction of task, distance and direction (mean  $\pm$  standard deviation).

way interaction of task, direction and distance showed that CME measures were able to distinguish texting from all other tasks except when texting was in front and far from the body (sagittal CME) and when texting was in front and close (lateral CME). It is possible that when considering the area under the curve for the general tasks, that even with shorter time of execution the magnitude of the moment was much higher than texting, thereby resulting in similar CMEs to texting (i.e. visual tasks, Figure 2). The length of time exposed to the biomechanical moment from texting was longer than other tasks, thus increasing the value of the CME. When texting, the individual is more likely to keep the phone stagnant to enhance visual focus, therefore rendering a longer exposure to the moment.

The CME was able to determine differences between texting and other general tasks when compared to measures of moment or head displacement alone. As a proof of concept to demonstrate the feasibility of the CME, a series of probability density plots of CMEs for increasing time points of texting were extracted (5 s, 10 s, 15 s and so on) (Figure 6). These plots were compared to the CME of all other tasks (weighted, non-weighted and visual targeting, lumped as one parameter). Interestingly, texting was detected in the lateral direction after 5 s with a 13% probability of misclassification and after 10 s, only 7%. In general, as time increased, misclassifications decreased. Hence, taking the measures of moment and time into

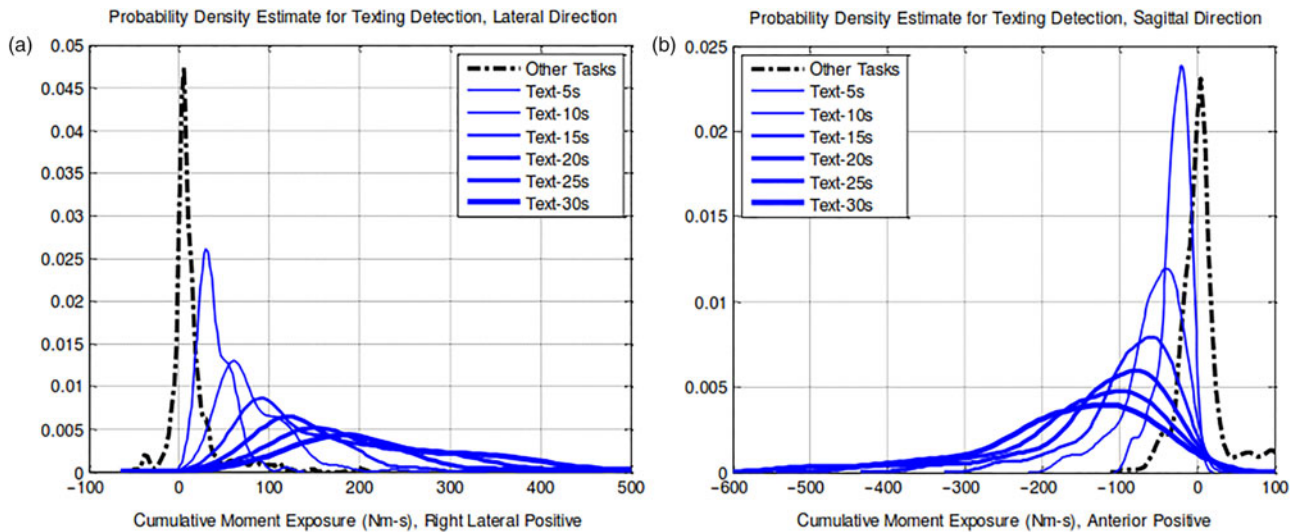


Figure 6. Sample probability density estimates of the CME at different times. The curves that denote texting become differentiable from the other tasks beginning at about 5 s. (A) Lateral CME and (B) sagittal CME.

consideration when implementing force sensors into seats may assist with determining distraction events and warn the driver of impending danger. Understanding the biomechanical signatures between different tasks may reduce potential for false alarms which may aggravate the driver more than assist. Future studies would be needed to define the thresholds as well as test the practicality of these measures in a naturalistic environment.

#### 4.1. Study limitations

In order to place this study into context, a few limitations should be noted. First, the study was run under laboratory conditions as well as with a simulated seat, and the results may change if the variables change, including individual biomechanical signatures. Static laboratory conditions were necessary in order to understand the biomechanical signatures of the distraction-related movements without confounding factors of vehicular vibration, driving conditions, etc. Task execution time was measured directly from the initiation of the task to the end of the task. Under naturalistic conditions, it is not clear a priori. However, when evaluating the CME at different time points, it was found that texting may be detectable by looking at the continuous data before the completion of the task (Figure 6). Future studies should validate these conditions under more naturalistic conditions. Second, the age range of the subjects was between 20 and 29 years old and did not address texting experience. A study by Tison, Chaudhary, and Cosgrove (2011) showed that the majority of the texting population was between 21 and 34 years old, with the riskiest population under the age of 25. Therefore, this study may have represented the best case scenario, as many of these subjects were experienced with texting. Older subjects may be less experienced with texting. Thus, the time that they may take to perform the task may be far greater as well as their style of texting. Future studies would also address the differences in ages. Third, subjects used their own phones. This was allowed in order to reduce the confounding effect of learning upon the CME.

#### 5. Conclusions

This study has shown that drivers engaged in a prescribed text-messaging task in a simulated car environment produce different biomechanical signatures in comparison to other simulated tasks. This suggests the possibility that biomechanical indicators may be used to detect text-messaging while driving in a real car. Further research is needed to understand how these indicators may be influenced by other factors when driving in a real car with text-messaging undertaken in a more naturalistic manner.

#### Disclosure statement

No potential conflict of interest was reported by the authors.

#### Notes

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