



A Field Study Assessing Driving Performance, Visual Attention, Heart Rate and Subjective Ratings in Response to Two Types of Cognitive Workload

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Summary

In an on-road experiment, driving performance, visual attention, heart rate and subjective ratings of workload were evaluated in response to a working memory (n-back) and a visual-spatial (clock) task. Subjective workload ratings for the two types of tasks did not statistically differ, suggesting a similar level of overall workload. Gaze concentration and heart rate showed significant changes relative to single task driving during the extra tasks and the magnitude of change was similar for both, while driving performance measures were not sensitive to the increase in workload. The results suggest high sensitivity of both gaze dispersion and heart rate as measures of workload across these two different types of cognitive demands.

Introduction

Driving is a complex psychomotor task which requires information processing, prompt decision making, and timely physical reaction to rapidly changing roadway demands. Increased usage of in-vehicle systems and roadway congestion result in an increase in cognitive workload for the driver (Embrey, 2000; Patten, et al., 2004; Kass, et al., 2007; Mehler, et al., 2012). Future vehicle systems are likely to monitor drivers' behaviors, eye movements, and/or physiological changes to assess workload (Boer, 2000; Nabo, 2009) and adjust vehicle systems and automation to optimize the level of driver demand for road safety (Coughlin, et al., 2011). Understanding how and to what extent different workload measures vary in response to different types of cognitive activities is a key step towards developing effective workload management systems.

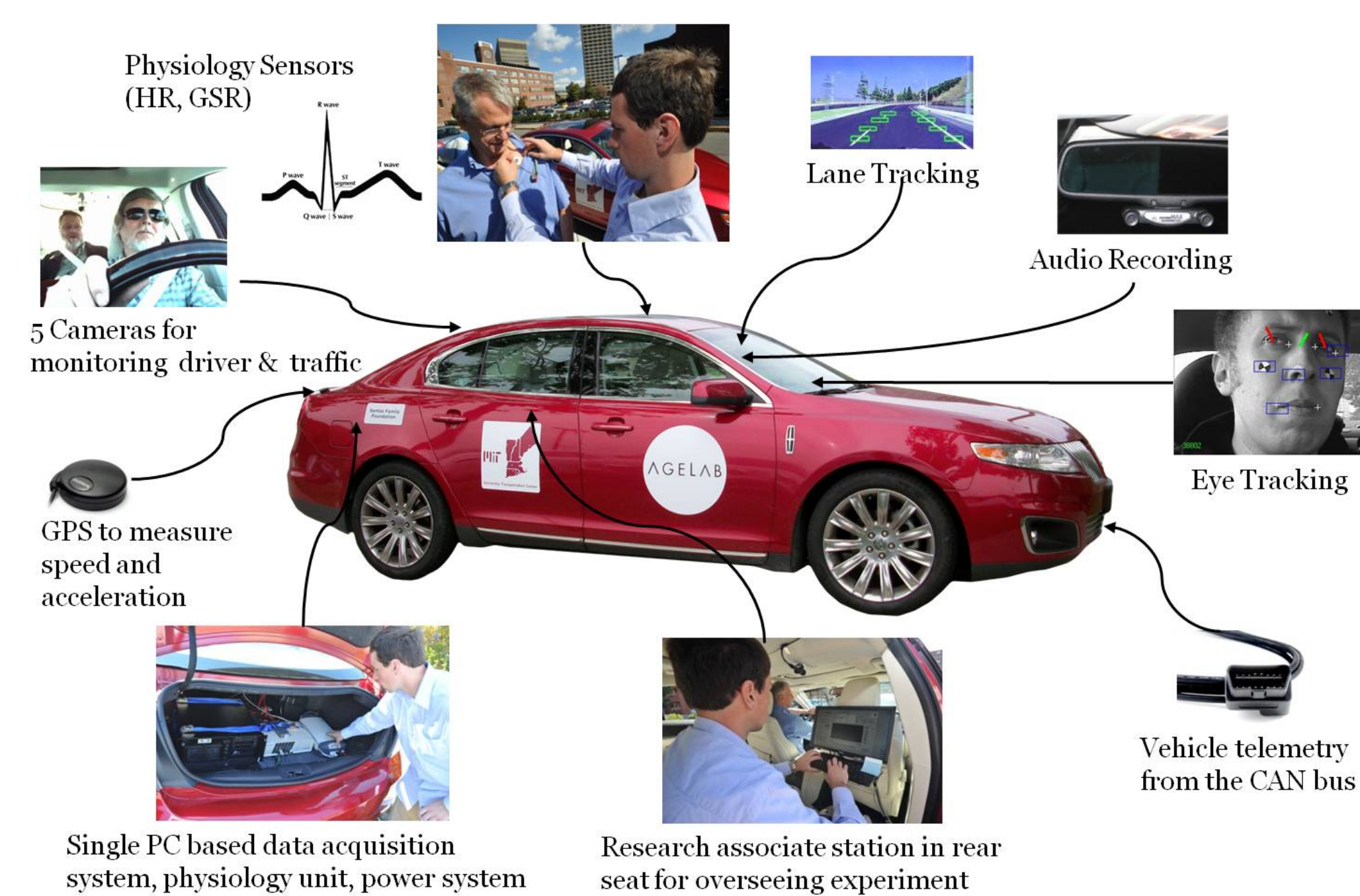
The main objective of the present paper is to evaluate the extent to which a cognitive task that calls upon mental resources that differ from those called upon by the n-back task produce similar or divergent patterns of response. The n-back task used in the previous studies calls upon the resources of working memory in the verbal/linguistic domain. For a comparison, a visual-spatial task, the Clock task (Schlorholtz & Schieber, 2006) was selected.

Method

Participants

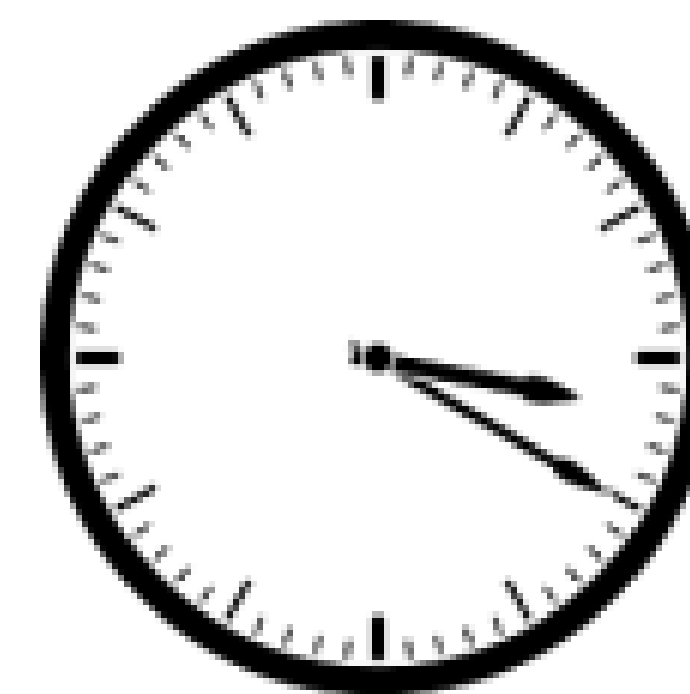
- 36 older adults (20 males), aged 60-75 (M=67.2; SD=5.3), in self-reported good health
- regular drivers (driving three or more times per week)
- free of police reported accidents for the previous year

Apparatus



Clock Task

- Visual-spatial task (Schlorholtz et al., 2006)
- Auditory presentation of a time as a number (i.e. 3:20); participants instructed to imagine the smaller angle between the hour hand and the minute hand on a clock face
- Verbal response 'yes' or 'no' as to whether the angle is larger than 90 degrees



1-Back Task

- Auditory presentation / verbal response working memory task
- Two 30-second blocks of 10 randomly ordered digits (0-9) with 2.25 sec inter-stimulus interval; recall and verbalize 1 number back in sequence

Present	2	3		5		6	...
Recall		x	2		3		5

Data Analysis

All measures were analyzed across 2 minute intervals for baseline driving and the secondary task periods. Driving performance and eye movement data were analyzed across the entire subject population, while heart rate data was assessed across 26 participants due to recording issues. Driving performance, heart rate, and gaze dispersion were tested for their sensitivity for discriminating workload levels. Correlation tests were then conducted.

Experimental Protocol

- Highway driving on I93 north of Boston, MA
- 20 minute habituation period before selected data collection
- 2 minutes each of the clock task and 1-back task were presented
- Subjective ratings of task difficulty were collected at the conclusion of the drive

Results

Subjective Workload Rating and Secondary Task Performance

On a scale of 1 to 10 where 1 was "very easy" and 10 "impossible", reported mean subjective difficulty ratings were 4.25 (SD=2.52) and 3.61 (SD=2.40) for the clock and 1-back tasks respectively. This perceived difficulty rating of the two tasks did not differ statistically (F(1,35)=2.38, p=.13). No significant difference in actual task performance was found (F(1,35)=1.55, p=0.22). Correct response rates were 86.6% (SD = 16.3%) for the clock trials and 91.4% (SD=17.7%) for the 1-back trials.

Driving Performance

MANOVA analyses showed that none of four driving performance measures was sensitive to the increased cognitive workload (speed: F(1,144)=.29, p=.59; SD speed: F(1,144)=.22, p=.64; micro-acceleration: F(1,144)=2.87, p=.09; steering wheel reversal rate: F(1,144)=.13, p=.72). No effect of drive segment was apparent (speed: F(1,144)=.56, p=.46; SD speed: F(1,144)=1.69, p=.20; reversal rate: F(1,144)=.35, p=.56) except for micro-accelerations (F(1,144)=5.63, p=.02) where the mean values were higher during the drive segment that included the clock task vs. the segment that included the n-back. No interaction effect was found.

Gaze Concentration

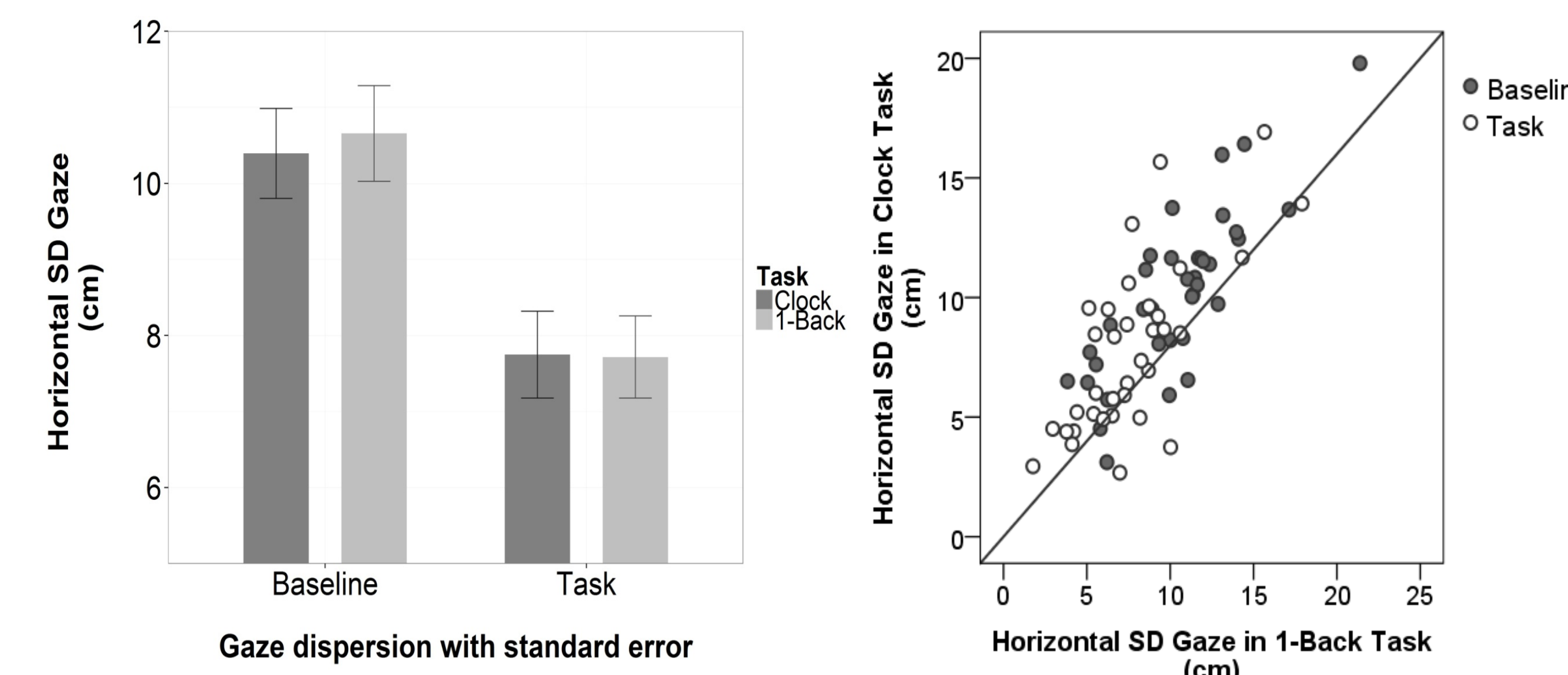


Figure 3. Horizontal gaze during single task driving and during Clock and 1-Back segments

Figure 4. Correlation of SD gaze during the Clock and 1-Back segments of the drive

- Reimer et al. (2012) found that horizontal gaze dispersion was sensitive to the demand of the 1-back task.
- Consistent with this, a significant main effect of condition (single task driving vs. added cognitive demand) appears (F(1,35)=37.27, p<.01).
- No main effect of drive segment (F(1,35)=.06, p=.81) or interaction between workload condition and drive segment appears (F(1,35)=.31, p=.58).
- Horizontal gaze dispersion is similar during two baseline reference periods and shows comparable concentration shift during tasks (Fig. 3).
- The consistency in the relationship between the relative horizontal gaze dispersion across the two driving segments considering both baseline and demand periods can be seen in the scatter plot in Figure 4.

Heart Rate

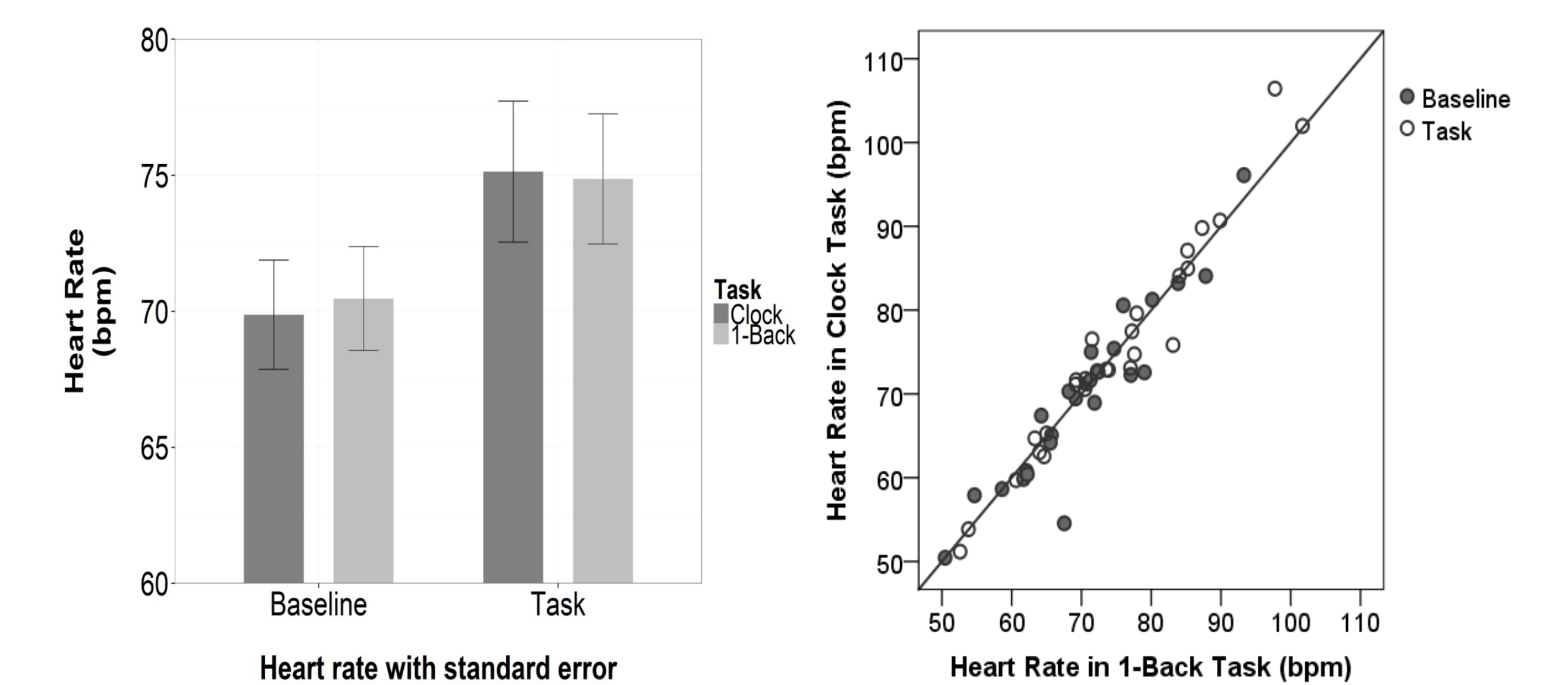


Figure 5. Heart rate during single task driving and during the Clock and 1-Back segments

Figure 6. Correlation of heart rate during the Clock and 1-Back segments of the drive

- It was previously reported that the heart rate increased in response to the 1-back working memory task (Mehler et al., 2012).
- Similarly, the present findings show an increase in heart rate with the added demands of the 1-back and clock tasks (F(1,25)=12.78, p<.01).
- There was no main effect of drive segment (F(1,25)=.14, p=.71) or interaction between workload condition and drive segment (F(1,25)=1.56, p=.22).
- No substantive differences appear in the heart rate during the two reference (baseline) periods or during the tasks (Fig. 5).
- Heart rate was closely correlated when both performing the clock and 1-back tasks and during two single task periods (Bivariate Pearson Correlation, r=.96, p<.001, see Fig. 6).

Discussion

In this study, driving performance, heart rate, and gaze dispersion were evaluated across two tasks with different neuro-cognitive components, i.e. visual-spatial representation and evaluation (clock task) vs. working memory (n-back). Horizontal gaze dispersion and heart rate were found to be sensitive to the added demand of both types of workload. Further, the results show consistency in the magnitude of the concentration of gaze and the increase in heart rate as a result of the two cognitive demands. None of the driving performance measurements were sensitive to changes in cognitive workload at the demand levels studied here. This work should be considered in light of potential limitations: the sample size is moderate and comprised of only older adults, and the presentation of the clock task prior to the n-back for all participants could conceivably have resulted in an order effect. However, in spite of these considerations, the pattern of behaviors observed appears to provide a clear illustration of the sensitivity and consistency of the eye based measure and heart rate to changes in cognitive workload.