Utilizing functional near-infrared spectroscopy to identify cognitive processes contributing to workload in a dual-task environment.

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Background

• Workload, or the amount of effort required to complete a task is difficult to characterize since tasks can be completed in multiple ways, are often dependent on the state of the actor or the environment, and often compounded by normal cognitive aging. That is, the amount of effort to complete a task varies.

• Previous research has shown that in dynamic environments such as driving while performing a secondary task, peripheral physiological measures (e.g heart rate, skin conductance levels) can capture changes in driver state and respond to increases in cognitive load (Mehler et al., 20). However both HR and SCL are non-specific to mental workload and can be affected by simple physical exercise.

• Managing workload is an important goal during real-world tasks such as driving or operating heavy machinary, but to truly manage workload we need to distinguish between simple arousal and the additional cognitive components including attention, working memory, task switching and learning.

• The ability to disentangle subtasks contributing to workload, could be possible by measuring cognitive activity directly. While imaging methods such as Magnetic Resonance Imaging (MRI) can help to identify processes which contribute to workload, they often come with great cost and limited real-world application.

• Functional near-infrared spectroscopy (fNIRS), enables similar measurements of cortical oxygen use but with reduced cost and inconvenience, similar spatial and better temporal resolution.

• This project utilized fNIRS in a real-world, dual-task environment (driving while performing a auditory-vocal working-memory task), in order to disentangle cortical processes contributing to workload.

• A secondary goal is to quantify and validate the use of this technology in more ecologically-valid settings than are traditional found in neurophysiological research.

Participants & Procedure

• 30 participants (17 female) active drivers (3X/week). Final dataset incouded 21Ps, 10 of whom were female.

• MIT AgeLab driving simulator is built on a fixed base, full cab 2001 Volkswagen Beetle. A 2.44m X 1.83m projection screen was positioned 1.93m in front of the windshield and provided an ~40-degree view.

• Physiological data was obtained from a MEDAC System/3 instrumentation unit (NeuroDyne Medical Corporation). Heart rate was derived from EKG using a modified lead-II placement (left & right clavicle and lower left rib). Non-polarizing, low impedance gold plated electrodes used for electrodermal sensors were placed on the underside of the middle fingers of the non-dominant hand. Physiological data was recorded at 250 Hz.

• The simulation was a divided highway with two lanes in each direction, posted speed limit was 65 mph (104.6 km/h).

• Each n-back set consisted of 10 single digit numbers (0-9), with each number being presented randomly once (ISI 2.25s). Eash task level was ~30 seconds in duration. Tasks were randomized withing wach block and brief rest given each block. Participants practiced until they were able to complete each level with at least 50% accuracy (i.e. no more than four errors on the 2-back).

• fNIRS data was collected using OxiplexTS(ISS Inc). Two probes were placed on the forehead of each participant approximately at the position Fp1-Fp2 of the international 10-20 system. Each source emits two light wavelengths (690nm and 830nm) to detect both oxygenated and deoxygenated hemoglobin. The source - detector distances were 1.5, 2, 2.5, and 3cm. The sampling rate was 6.25Hz throughout.

• A block average was computed using the 20 seconds before the first task as baseline. Then the first five seconds of the 30s task were removed since the full memory load for the 1- and 2-back conditions are not obtained until the 1st and 2nd stimuli are presented, respectively 2-back does not officially start until then. (thus, 25s per task condition).

• Summed absolute value of Steering Wheel Reversals (SWR) and the Standard Deviation of Lane Position (SDLP) were calculated as measures of driving performance.

Methods

Fig 1. Equipment with fNIRS, stimulus display, simulation

Fig 2. OxiplexTS (ISS Inc.) Each source emits two light wavelengths (690/830nm) to detect both oxygenated and deoxygenated hemoglobin. Source - detector distances were 1.5, 2, 2.5, and 3cm

Stimulus	5	7	0	9	8	4	3	1	2	6
Blank-back Response	-	-	-	-	-	-	-	-	-	-
0-back Response	5	7	0	9	8	4	3	1	2	6
1-back Response	-	5	7	0	9	8	4	3	1	2
2-back Response	-	-	5	7	0	9	8	4	3	1

Table 1. Example N-Back Set with Expected Response for Each Task

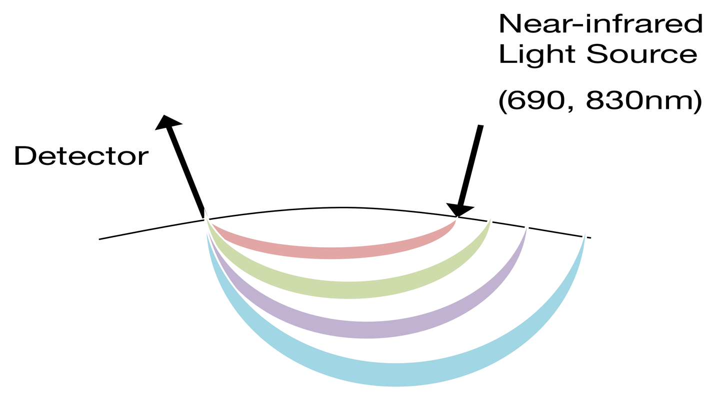
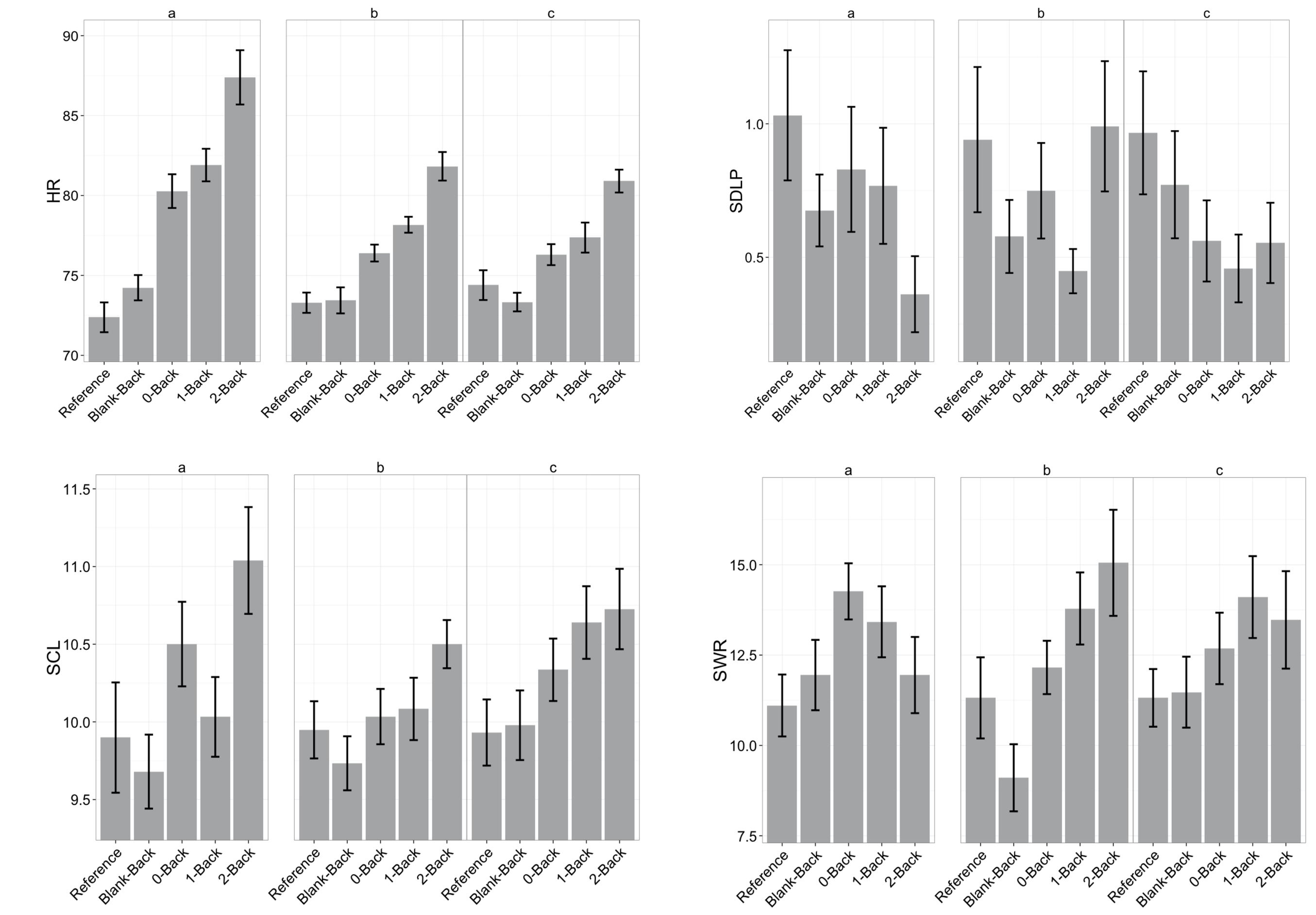


Fig 3. Source Detector Schematic

Results

Results



• Participants performed worse in the task as difficulty increased (0=back M=100%; 1-back M= 96.6%, SE=1.4%; 2-back M=90.7, SE=3.13) ($\chi 2$ (4)=25.68, p<.05).

• Heart rate increased signifcantly by task Reference M=73.7(3.1) < 0-back M=78.0 (3.1) < 1-back M=79.8 (3.22) < 2-back M= 82.9 (3.14) ($\chi 2$ (4)=33.27, p<.01)

• SCL increased signficantly by task Reference M=9.72(79) < 0-back M=10.1(0.84) < 1-back M=10.01 (87) < 2-back M=10.5(82). ($\chi 2$ (4)=9.97, p<.01).

• Min HbR was also a good indicator of task level with signficant differences found for sensors S1, S2, S3, S6, S7 in predicted order of ref < blank < 0-back < 1-back < 2-back

• Max HbO showed no significance differences across task level

• Only HR showed sig. effects across blocks, however different NIRS sensors were affected differently over time. Average HbO did increase sig. across blocks.This appears largely driven by changes at the 2-back level.

Discussion

• While HbR may be a better indicator of task level, HbO may be better indicator of changes in task types, and may indicate changes in cortical areas (e.g. DLPFC v. VLPFC, BA9/10 etc.)

• Similar to block b here, Callicot (1990) recorded FMRI during an nback task and found areas in dorsolateral prefrontal cortex (DLPFC) showed an 'inverted-U' shaped response from lowest to highest level. While Callicot reached capacity by 3back, we have additional task of driving, so perhaps capacity was reached earlier.

• A meta-analysis (Wager and Smith, 2007) found: 'Brodmann's areas 6, 8, and 9, in the superior frontal cortex, respond when WM must be continuously updated and temporal order must be maintained'. Right BA10 (~S1-4), in the ventral frontal cortex responded to dual-tasks or 'mental operations'

• BA10 was also engaged when application of one cognitive function was not sufficient to perform a task (Ramnani & Owens, 2004)

• As stratgies develop and Ps become better at task, it is possible what was once a very difficult task (2-back in block a) becomes manageable by block c. This would be reflected in the change from HbO decreases to HbO increases

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