A new neuropsychological instrument measuring effects of age and drugs on fitness to drive: development, reliability, and validity of MedDrive

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Abstract

Background
Current guidelines underline the limitations of existing instruments to assess fitness to drive and the poor adaptability of batteries of neuropsychological tests in primary care settings.

Aims
To provide a free, reliable, transparent computer based instrument capable of detecting effects of age or drugs on visual processing and cognitive functions.

Methods
Relying on systematic reviews of neuropsychological tests and driving performances, we conceived four new computed tasks measuring: visual processing (Task1), movement attention shift (Task2), executive response, alerting and orientation gain (Task3), and spatial memory (Task4). We then planned five studies to test MedDrive's reliability and validity. Study-1 defined instructions and learning functions collecting data from 105 senior drivers attending an automobile club course. Study-2 assessed concurrent validity for detecting minor cognitive impairment (MCI) against useful field of view (UFOV) on 120 new senior drivers. Study-3 collected data from 200 healthy drivers aged 20-90 to model age related normal cognitive decline. Study-4 measured MedDrive's reliability having 21 healthy volunteers repeat tests five times. Study-5 tested MedDrive's responsiveness to alcohol in a randomised, double-blinded, placebo, crossover, dose-response validation trial including 20 young healthy volunteers.

Results
Instructions were well understood and accepted by all senior drivers. Measures of visual processing (Task1) showed better performances than the UFOV in detecting MCI (ROC 0.770 vs. 0.620; p=0.048). MedDrive was capable of explaining 43.4% of changes occurring with natural cognitive decline. In young healthy drivers, learning effects became negligible from the third session onwards for all tasks except for dual tasking (ICC=0.769). All measures except alerting and orientation gain were affected by blood alcohol concentrations. Finally, MedDrive was able to explain 29.3% of potential causes of swerving on the driving simulator.

Discussion and conclusions
MedDrive reveals improved performances compared to existing computed neuropsychological tasks. It shows promising results both for clinical and research purposes.

Introduction

Studying effects of drugs on driving performance remains challenging. Merging principles from neuroscience, cognitive psychology, and ergonomics provide a solid translation approach to study the complexity of multiple cognitive processes engaged during driving (Lees, Cosman, Lee, Fricke, & Rizzo, 2010; Parasuraman & Wilson, 2008). Computational neuroergonomics has shown promising results in its capacity to model cognitive functions and predict driving difficulties (Aksan et al., 2012; Liu, Wu, & Berman, 2011). This has now made it possible to translate results from computed tests, such as the useful field of view (UFOV) (Ball et al., 2006; Hoffman, McDowd, Atchley, & Dubinsky, 2005) or the attention network task (ANT) (Weaver, Bedard, McAuliffe, & Parkkari, 2009), to real-life situations that can be observed when driving (Lees, et al., 2010). Recent technological advances in home-computer processing time have opened the field of cognitive screening for effects of age or medication on driving in primary care settings. This has led us to develop a new instrument to detect effects of natural cognitive decline or drugs on cognition functions indispensable for driving.

Developing MedDrive

Conceptual framework

MedDrive is a software that was programmed on C++ for personal computers on either Windows or Mac OS. It includes four computed neuropsychological tasks. The first three tasks were inspired from the UFOV, and the ANT. The UFOV has been shown to be one of the best predictors of driving difficulties. It is however designed for senior drivers and is not adapted to be used with younger drivers.(George & Crotty, 2010; Hoffman, et al., 2005; Mathias & Lucas, 2009; Silva, Laks, & Engelhardt, 2009) Using Posner's model of attention,(Jennings, Dagenbach, Engle, & Funke, 2007; Lopez-Ramon, Castro, Roca, Ledesma, & Lupianez, 2011; Posner & Rothbart, 2007) the ANT has been shown to measure different dimensions of attention than the UFOV (Weaver, et al., 2009). The ANT uses a single stimulus to measure simultaneously top-down arousal related to alertness or orientation, and frontal executional modulation related to coherent or incoherent visual information. We have however decided to separate these measures as it has been shown that they tend to interact one with another.(Fan, McCandliss, Sommer, Raz, & Posner, 2002; Macleod et al., 2010; McConnell & Shore, 2011) This has made it possible to improve the design of the paradigm and integrate movement detection instead of shape discrimination. The fourth task investigates spatial working memory (Olivers, Peters, Houtkamp, & Roelfsema, 2011; Ruchkin, Grafman, Cameron, & Berndt, 2003) MedDrive therefore combines visual processing, attention, executive functions, and working memory that have all been recognised as essential for driving (AMA/NHTSA, 2003; Bula, Eyer, von Gunten, Favrat, & Monod, 2011; Iverson et al., 2010; Messinger-Rapport, 2003; Mosimann et al., 2012; Murden & Unroe, 2005; Odenheimer, 2006; Sherman, 2006).

Calibrating tasks and formulating instructions

For visual processing (Task 1), images were exposed 500 times at 50ms and then modified until the prevalence of errors was equivalent for all image types. To achieve this, 8,500 exposures were needed. To measure the psychometric function of visual processing separately for each image type, three healthy young volunteers repeated measures 500 times for each of the following duration of exposure; 217ms, 150ms, 117ms, 83ms, 67ms, 50ms,

33ms, 17ms. Learning effects were diminished by having each volunteer run tests at least 10 times before measures were taken into consideration.

Instructions for each task were modified and tested on 106 senior drivers attending a course organised by the Swiss Automobile Association. During this phase, the arrows in the peripheral visual perception task were adapted to this population and increased in size. The final standardised version of instructions was used on 109 senior drivers. Participants were all able to perform tasks, even for those with mild cognitive impairment. The average time required to do all four tasks was of approximately 45 min with the instructions. In research settings, MedDrive requires 16'33''.

Parallel forms

When driving, the localisation of an important visual stimulus is discovered at the same time as it appears. It therefore seemed important to test the effect of using randomised sequences of central, peripheral or dual images in the visual processing task (Task 1). In young healthy drivers, using random sequences increased the threshold for central vision processing by 24.6%, peripheral vision processing by 165.7%, and dual tasking by 22.8%. Nevertheless, the association to blood alcohol concentrations (BAC) and central processing threshold was twice better when tasks were not at random (R^2= 0.133 vs. R^2=0.067). However, using random mode made the task more sensitive in detecting effects with a BAC at 0.5g/L. On the other hand, central visual processing alone showed a better association to standard deviation of lateral position (SDLP) on the driving simulator without the random mode (R^2= 0.162 vs. R^2=0.040).

Orientation and alerting gain (Task 3) were subject to learning bias as the lapse of time between the exposure of the alerting or orientation cue and the response cue was constant. We therefore compared results after implementing a random lapse between both cues. The task's performance in measuring orientation gain was thereby improved.

MedDrive's reliability and validity

Reliability

Reliability was assessed by having 21 healthy participants (9 male, 11 female) repeat all tasks five times. Participant's age ranged from 23 to 39 years (median of 25 years). The first measures were done on a PC with a 22-inch LCD screen. All other measures were done on participants' personal computers. Reliability ranged from ICC=0.376 for central visual processing threshold (Task1) to ICC=0.818 for movement attention shift (Task2). This is partially explained by the fact learning effects were important for tasks related to visual processing. For all other tasks, learning effects become negligible after the second measure.

Concurrent validity

We tested 109 drivers of which 35 had a Monreal Cognitive Assessement (MoCA) score <26 points considered as minor cognitive impairement. MedDrive's central visual processing (AUC=0.770) was significantly better at detecting those with mild cognitive impairment (p=0.048) than the UFOV (AUC=0.620). Furthermore, when modelling age in 61 healthy drivers, MedDrive was capable of explaining 43.4% of observed variance due to natural cognitive decline.

The benefit of MedDrive over the UFOV was even more evident when modelling performances on the driving simulator. SDLP was measured for 20 young healthy drivers who were not under the influence of any substances. MedDrive was able to explain 29.3% of observed variance of SDLP whereas UFOV only explained 0.5% thereby largely improving our ability to assess fitness drive in younger populations ($p=0.003$).

Responsiveness to alcohol

We organised a randomised, double blind, placebo, crossover, dose-response validation trial including 20 young healthy drivers (NCT01781273). Participants were given 1L of cranberry juice containing 96% ethanol to randomly bring their BAC to 0.0g/L, 0.5g/L, 0.65g/L or 0.8g/L. All tasks within MedDrive were affected by alcohol absorption. Central vision processing was affected from a BAC of 0.65g/L (+11.9%, $p=0.002$). In random mode, central visual processing was affected earlier (BAC=0.5 g/L; +6.9%, $p=0.034$). Movement detection and attention shift were affected with a BAC at 0.65 g/L (+10.3%, $p=0.030$), executive response time with a BAC at 0.8 g/L (+16.7%, $p<0.001$), and spatial memory with a BAC at 0.65 g/L (+15.6%, $p=0.001$).

Future perspectives

MedDrive reveals promising properties for both clinical and research purposes. Improvements in calculating thresholds in the visual processing task are under way to improve the task's reliability. Large cohort studies are needed to evaluate MedDrive's ability to predict risks of on road-accidents and improve age specific normative data. The software is already made available for research purposes at www.medDrive.org.

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