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**Modeling Perceptual Decision Processes**

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Final Report**

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## Final Report

The two-choice diffusion model has been applied widely in psychology and neuroscience and three packages have been developed to allow the model to be fit to data. We decided to do a systematic examination of these packages along with an evaluation of individual differences and the effects of the number of observations on parameter recovery. These issues are critical if the modeling approach is to be used to assess individual differences. The article is 100 pages long and has received a positive review from the new APA journal *Decision*. It will require some rewriting to reduce the length and provide a more gentle introduction.

The project examined methods for fitting the diffusion model to data. There are three parts to the paper. The first part examines practice effects and the ability of the model to recover parameter values with low numbers of observations in two experiments that have designs that might be used in practical applications. There is a lot of stability in estimated parameters even with quite low numbers of observations which came as somewhat of a surprise. The second part uses simulated data with parameters from the same ranges as those in the two experiments and examines recovery of individual differences from 7 different fitting methods (including 4 published packages). The third part examines bias and accuracy of parameter recovery. For the two designs, 48 sets of parameter values that span the range of those seen in fits to data were used to generate 64 simulated subjects per group. The model was fit with the different packages. Results showed that some of the methods were quite a bit superior to other methods. Finally, a hierarchical Bayesian package was used to fit simulated data from the second (individual differences) study and costs and benefits were examined.

From these results, a potential user of the model can get a feel for the power of analyses they can get from their designs. The user can also determine what individual differences they may be able to detect.

With Hans Van Dongen, we completed a study of the effects of sleep deprivation on memory, specifically item recognition and associative recognition (Ratcliff & Van Dongen, submitted). We picked these two tasks because they are used extensively in modeling memory processes, and because past literature suggests that they might be differentially affected by sleep deprivation. Also, memory is a component in many practical situations, it is important to see how it is affected in sleep deprivation and to see which components of the memory tasks are affected.

Our results showed a decrease in drift rate (evidence used in making the decision) and no effect on the other model parameters. For example, under sleep deprivation, there seemed to be no change in the amount of evidence the subjects required to make a decision and there was no change in the duration of encoding and response output processes. A paper on this is under review. We have also performed a similar experiment on perceptual tasks and these await time for modeling.

One major effort has been on driving tasks. One paper was published (Ratcliff & Strayer, 2014) and another is under review. Data from two more studies have been collected and initial modeling done. These only require time for writing and final modeling to produce articles for submission. The aim of these studies was to show how the decision models could be applied in experiments using simulator environments.

The published paper applied the one-boundary diffusion model to the data from two experiments in which subjects were performing a simple simulated driving task. In the first experiment, the same subjects were tested on two driving tasks using a PC-based driving simulator and the psychomotor vigilance test (PVT - a task used extensively in sleep research, see Ratcliff & Van Dongen, 2011, PNAS). The diffusion model fit the response time (RT) distributions for each task and individual subject well. Model parameters were found to correlate across tasks which suggests common component processes were being tapped in the three tasks. The model was also fit to a distracted driving experiment of Cooper and Strayer (2008). Results showed that distraction altered performance by affecting the rate of evidence accumulation (drift rate) and/or increasing the boundary settings. This provides an interpretation of cognitive distraction

whereby conversing on a cell phone diverts attention from the normal accumulation of information in the driving environment.

In the submitted paper, an experiment is presented in which subjects were tested on both one-choice and two-choice driving tasks and on non-driving versions of them. Diffusion models for one- and two-choice tasks were successful in extracting from response time and accuracy data measures of the quality of the information from the stimuli that drove the decision process (drift rate in the model), for the two-choice model, the speed/accuracy criteria subjects set, and the time taken up by processes outside the decision process. Drift rates were only marginally different between the driving and non-driving tasks, indicating that nearly the same information was used in the two kinds of tasks. The tasks differed in the time taken up by other processes, reflecting the difference between them in motor aspects of performance. Drift rates were significantly correlated across the two two-choice tasks showing that subjects that performed well on one task also performed well on the other task. Nondecision times were correlated across the two driving tasks, showing common abilities on motor processes across the two tasks. These results show that diffusion decision modeling can be used to decompose performance in one-choice and two-choice driving tasks into its underlying components and so allow the loci of the effects of factors that impair driving to be determined.

In the first study to be written, there were three tasks. The first was a one-choice task: drive into the adjacent lane when the car in front puts its brake lights on. The second was a two-choice task: when an array of black and white pixels appears, drive to the right lane if it is bright and the left lane if it is dark. The third was the same as the second except instead of being in a relatively featureless open road, the car was in a city with buildings, instructions to turn corners, and with night time limited visibility, in other words a more complicated and distracting environment. Results show correlations in model parameters that show consistent individual differences across tasks and the effect of the distracting environment was to reduce drift rates, i.e., there was poorer information from the stimulus with which to make the decision than in the clear environment.

In the second study to be written, we performed a speed-accuracy manipulation with one-choice and two-choice tasks. This experiment has to be modeled in detail yet. Preliminary results show the expected effects of the speed-accuracy manipulation on decision criterion settings.

I was also involved in model fitting for an experiment on the effects of video gaming on decision making (van Ravenzwaaij, Boekel, Forstmann, Ratcliff, & Wagenmakers, in press). Previous research suggests that playing action video games improves performance on sensory, perceptual, and attentional tasks. For instance, Green, Pouget, and Bavelier (2010) used the diffusion model to decompose data from a motion detection task and estimate the contribution of several underlying psychological processes. Their analysis indicated that playing action video games leads to faster information processing, reduced response caution, and no difference in motor responding. Because perceptual learning is generally thought to be highly context-specific, this transfer from gaming is surprising and warranted replication in a large scale training study. We conducted two experiments in which participants practiced either an action video game or a cognitive game in five separate, supervised sessions. In the second experiment we included a third condition in which no video games were played at all. Behavioral data and diffusion model parameters showed similar practice effects for the action gamers, the cognitive gamers, and the non-gamers and suggest that, in contrast to earlier reports, playing action video games does not improve the speed of information processing in simple perceptual tasks.

We have also developed a model for the go/no-go task. It is a task with a long history in experimental psychology and has clinical applications. For the Air Force, it is a task that is quite common in many domains. For example, if a stimulus appears, the subject either has to perform an action or withhold any response. In contrast, in a two-choice task, subjects are presented with a stimulus and are required to make one of two responses based on the stimulus (e.g., is this stimulus bright or dark, was this word studied before, and so on).

The model we developed is one in which subjects adopted two decision boundaries but did not implement one decision. The hypothesis is that subjects make both decisions but do not make a no-go response and so wait out no-go trials until time-out expires. We fit the go/no-go model to half of the data from a two-choice task (mimicking go/no-go data) and found model parameters close to those for the two choice task except for the time taken for nondecision processes (which can be interpreted as: the motor component of processing is faster for hitting one key than for hitting one of two keys). We fit go/no-go data from the same subjects as the two-choice data and found that drift rates were reduced, that is, evidence from the stimulus had lower quality when faced with a go versus no-go decision than when making one of two responses to the two choices in the two-choice task.

With Philip Smith we have continued investigation of integrating models of perceptual processing with the decision models and a paper is in press from this collaboration (Smith, Ratcliff, & Sewell). We have found that the speed and accuracy of discrimination of featurally-defined stimuli such as letters, oriented bars, and Gabor patches are reduced when they are embedded in dynamic visual noise. But, unlike other discriminability manipulations, dynamic noise produces significant shifts of RT distributions on the time axis. These shifts appear to be associated with a delay in the onset of evidence accumulation by a decision process until a stable perceptual representation of the stimulus has formed. We considered two models for this task, which assume that evidence accumulation and perceptual processes are dynamically coupled. One is a time-changed diffusion model in which the drift and diffusion coefficient grow in proportion to one another. The other is a release from inhibition model, in which the emerging perceptual representation modulates an Ornstein-Uhlenbeck decay coefficient. Both models successfully reproduced the families of RT distributions found in the dynamic noise task, including the shifts in the leading edge of the distribution and the pattern of fast errors. We concluded that both models are plausible psychological models for this task.

We published a new model for multichoice decisions and confidence judgments (Ratcliff & Starns, 2013). Confidence in judgments is a fundamental aspect of decision-making and tasks that collect confidence judgments are an instantiation of multiple-choice decision-making. The model was applied to confidence judgments in recognition memory tasks. The model uses a multiple-choice diffusion decision process with separate accumulators of evidence for the different confidence choices. The accumulator that first reaches its decision boundary determines which choice is made. With this algorithm, an increase in the evidence in one accumulator is accompanied by a decrease in the others so that the total amount of evidence in the system is constant. Application of the model to the data from an earlier experiment (Ratcliff, McKoon, & Tindall, 1994) uncovered a relationship between the shapes of z-transformed receiver operating characteristics and the behavior of response time distributions. Both are explained in the model by the behavior of the decision boundaries. For generality, we also applied the decision model to a three-choice motion discrimination task and found it accounted for data better than a competing class of models.

I also examined psychometric functions with the diffusion model (Ratcliff, 2013). In the paper, the diffusion model was fit to a range of perceptual tasks (11 experiments). Psychometric functions for these tasks usually plot accuracy against difficulty, but for some levels of difficulty, accuracy can be at ceiling. The diffusion model extends the range of difficulty that can be evaluated because drift rates depend on response times (RTs) as well as accuracy and when RTs decrease across conditions that are all at ceiling in accuracy, then drift rates will distinguish among the conditions. Signal detection theory assumes that the variable driving performance is the z-transform of the accuracy value and somewhat surprisingly, this closely matches drift rate extracted from the diffusion model when accuracy is not at ceiling, but not sometimes when accuracy is high. Even though the functions are similar in the middle of the range, the interpretations of the variability in the models (e.g., perceptual variability, decision process variability) are incompatible.