

BEHAVIORAL CORRELATES OF PERCEPTUAL CONFIDENCE IN A MOTION
TRACKING PARADIGM

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PLAGIARISM

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ABSTRACT

Perceiving motion of objects around the environment requires understanding of several features of motion such as direction, speed, and density. In this process, we rely both on the sensory input and our confidence level regarding our decision about the features of motion. However, the signal reaching our senses is not always entirely intact hence it includes noise. In this context, signal-to-noise ratio affects both motion detection and perceptual confidence. In this study, I examined the effect of signal-to-noise ratio on motion detection accuracy and perceptual confidence with the Continuous Perceptual Task Paradigm (CPR). Participants were asked to hit a target with a joystick that randomly appeared on the outer diameter of a circular random dot cinematogram (RDC). In addition, individuals were prepared for the main experiment by applying the Reaction Time (RT) task and 4 Alternative Forced Choice (4AFC) tasks before the main experiment. I found out that radial joystick accuracy increased with increasing signal-to-noise ratio. Also, joystick strain increased with increasing signal-to-noise ratio. These results indicate that perceptual confidence and motion detection accuracy rely on the availability of the information about the direction of motion.

Keywords: motion perception, perceptual confidence, motion detection, perceptual learning

ÖZET

Çevredeki nesnelerin hareketini algılamak, yön, hız ve yoğunluk gibi çeşitli hareket özelliklerinin anlaşılmasını gerektirir. Bu süreçte hem duyuşal girdilere hem de hareketin özellikleriyle ilgili kararlarımıza ilişkin güven düzeyimize güveniriz. Ancak duyularımıza ulaşan sinyal her zaman tam olarak bozulmamış değildir, dolayısıyla gürültü içerir. Bu bağlamda, sinyal-gürültü oranı hem hareket algılamayı hem de algısal güveni etkiler. Bu çalışmada, Sürekli Algısal Görev Paradigması (CPR) ile sinyal-gürültü oranının hareket algılama doğruluğu ve algısal güven üzerindeki etkisini inceledim. Katılımcılardan dairesel rastgele nokta sinematogramının (RDC) dış çapı üzerinde rastgele görünen bir joystick ile bir hedefi vurmaları istendi. Ayrıca ana deneyden önce Reaksiyon Süresi (RT) görevi ve 4 Alternatif Zorunlu Seçim (4AFC) görevi uygulanarak bireyler ana deneye hazırlandı. Radyal joystick doğruluğunun artan sinyal-gürültü oranıyla arttığını öğrendim. Ayrıca, artan sinyal-gürültü oranı ile joystick gerilimi arttı. Bu sonuçlar, algısal güven ve hareket algılama doğruluğunun, hareket yönü hakkındaki bilgilerin mevcudiyetine bağlı olduğunu göstermektedir.

Anahtar kelimeler: hareket algısı, algısal güven, hareket tespiti, algısal öğrenme

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1.INTRODUCTION

Moving objects constitute an important and large part of visual perception process. We try to estimate the speed, direction, and other features of motion in order to understand the true nature of the stimulus. Visual motion perception is one of the main ways humans use to understand the movement in the outside world. Brain processes the incoming signals to reveal the features or even intentions of the moving object as it poses a crucial importance in survival and in our understanding of the environment. Different strategies and mechanisms are used in this process to facilitate and quicken the estimation. Although different aspects of motion perception have been studied, these strategies which are tied to the perceptual confidence are not investigated well in this scope. In this aspect, answering the question of how we perceive motion would reveal fundamental mechanisms of human cognition and perception.

1.1. Visual Perception

Sensation and perception are the most basic cognitive processes. Stimuli are received from our surroundings through the sensory organs and transmitted to the relevant regions in the brain and interpreted as a result of processing. However, the process of receiving each stimulus from outside and transmitting it to the relevant parts of the brain is different from each other.

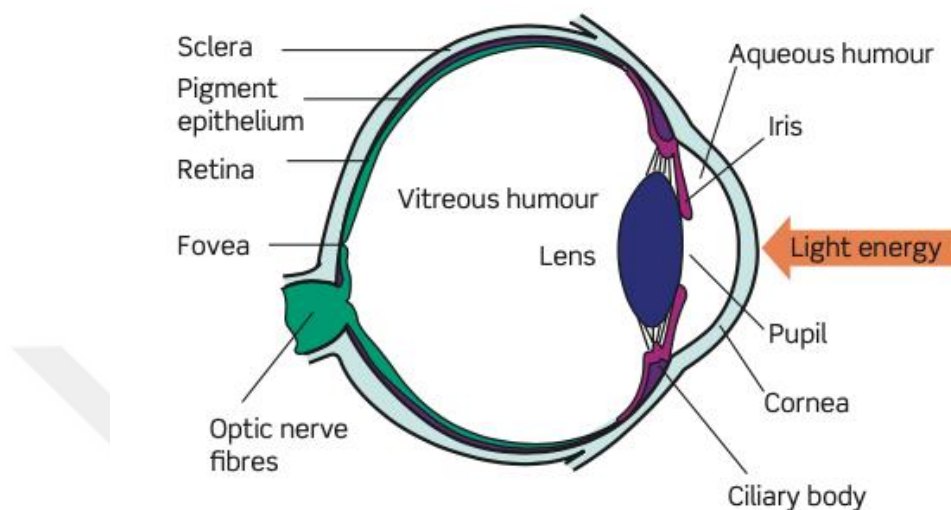


Figure 1: Anatomy of the eye.

The light from the environment first comes to the cornea, which is in the anterior part of the eye. Behind the cornea is the anterior chamber. It contains a liquid called aqueous humor and this liquid creates a pressure. The light received by the cornea is transmitted to the iris, which is the colored part, and to the lens, passing through the pupil in the middle of the iris. Behind the lens is a highly concentrated liquid called vitreous humor. (Swanston, & Wade, 2001; Snowden, Thompson & Troscianko, 2012).

With the light reaching the photoreceptors in the retina, neural processing begins. The information from the eye is transmitted via the ganglion cells to the visual cortex. There are two types of photoreceptors called rods and cones. Rods have pigments called rhodopsin. As the light level decreases, the activation of the rods increases, while the activation of the cones increases with the increase in the light. Thus, it is known that rods are more sensitive to light. Cones are densely located in the middle of the fovea while

rods are located more peripherally. There is a place on the fovea called the blind spot where there are no ganglion cells. Thus, the light passes through the eye and continues to the cortex (Dowling, 1987; Roorda, & Williams, 1999; Hadjikhani, & Tootell, 2000).

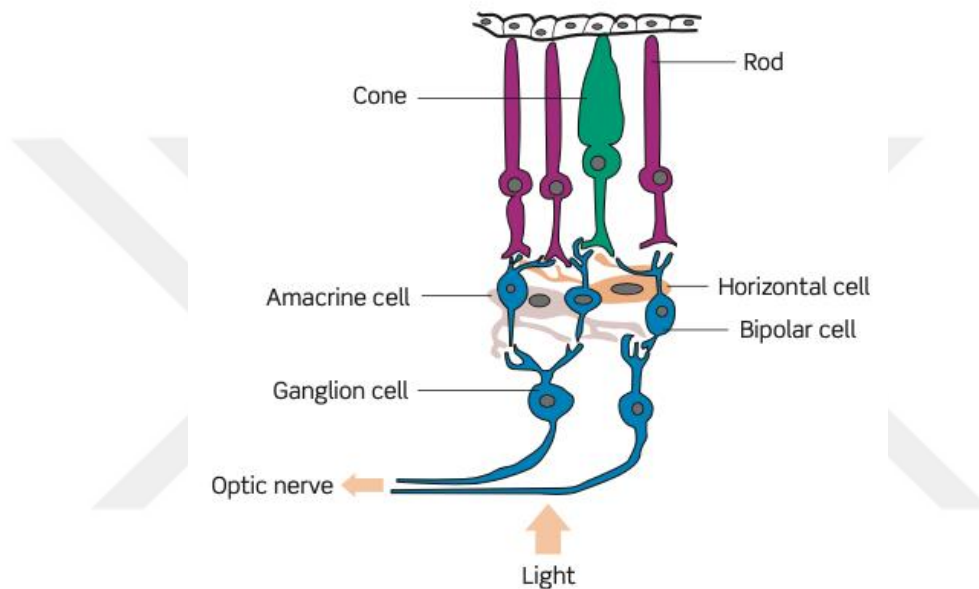


Figure 2: Photoreceptors and other cells in retina

The information from the two eyes does not reach the cortex directly. Optic nerves coming from the right and left eyes cross in the region called optic chiasm. Information from the right eye is transmitted to the lateral geniculate nucleus (LGN) located on the left side, while information from the left eye is transmitted to the lateral geniculate nucleus (LGN) located on the right side. This is called contralateral transmission (Hubel, 1988; Snowden, Thompson & Troscianko, 2012; Andrews, Halpern, & Purves, 1997).

After the optical chiasm, the visual signal reaches the primary visual cortex (V1, striate cortex). A simple level of processing is performed in V1, where the information first arrives in the cortex, and is transmitted to the more specialized extrastriate cortex (Hubel, 1963; Livingstone, & Hubel, 1988).

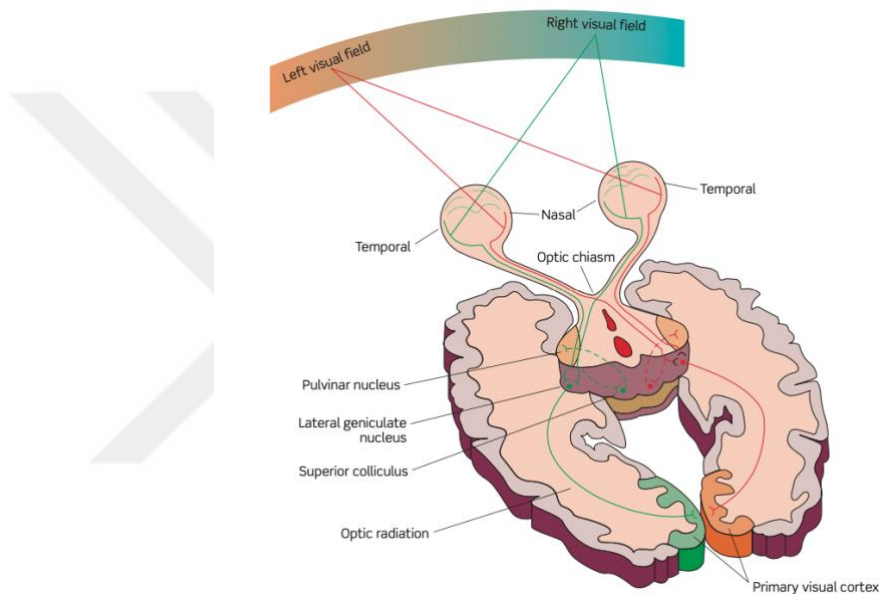


Figure 3: The visual pathway

Studies show that there are more than 30 extrastriate areas behind V1. All these areas are specialized for different forms of visual information. Although it is known that the V4 region is specialized for color and the V5 region is specialized for motion, there are studies showing that the V3 region is specialized for form and the V9 region is specialized for eye movements (Snowden, Thompson & Troscianko, 2012). There are many complex pathways consisting of these connections. Dorsal and ventral pathways, also known as "what" and "where" pathways, are the most well-known ones. The ventral

stream associated with object recognition is known as the "what" pathway, as it provides information about what the object is. The dorsal stream, on the other hand, is called the "where" pathway because it processes information about the location of the object (Riesenhuber, & Poggio, 1999; Goodale, & Milner, 1992; Milner, & Goodale, 2006).

Although it is known that the V5 region is mainly responsible for motion perception, there are other areas associated with movement. Studies show that the MT/V5 area in the inferior temporal sulcus in humans is activated by visual movement ((Newsome, Britten, & Movshon, 1989). In non-human primates, the MT and MST regions are homologous to the MT/V5 region (Zeki, 1992; Zeki, et, al, 1991; Tootell, et. al., 1996). Martinez-Trujillo et. al. (2005) showed in their studies that the MT/V5 region in humans is activated by visual movement. They also proved that the MT/V5 region is more activated in the accelerated unidirectional movement pattern. In addition, they showed that this region, which corresponds to MT in monkeys, also plays an active role in the perception of speed.

1.2. Visual Attention

Visual information received through the eyes is the first step of visual perception. Attention plays a major role in the process of receiving information from outside. There is a lot of research showing that attention influences sensory signals in the extrastriate cortex (e.g., Treue, 2003; Moran, and Desimone, 1985). In electrophysiology and neuroimaging studies, they have been proven that attention affects the activation in V1 (Motter, 1993; Hillyard, et. al., 1999; Seiffert, et. al., 2003). This affects bottom-up

processing, which is the process of extracting visual information directly from the incoming signals. Also, attention has the effect of moderating the top-down processing. It also has a directing effect on visual features (Maunsell, & Treue, 2006). This shows the effect of attention on perception. For example, many visual features such as color, speed, direction, and size can attract attention. In addition, a random dot pattern with different levels of coherence was used in literature, and the effect of spatial attention on MT neurons was observed regardless of signal to noise ratio (Daliri, Kozyrev, & Treue, 2016; Albright, 1984; Movshon, & Newsome, 1992).

1.3. The Perception of Motion

In the real world, we are continuously exposed to movement. The perception of movement is crucial for survival. The fact that all animals realize the threat and react accordingly basically constitutes the fight or flight response. Then how does the perception of motion start? In particular, the perception of visual motion begins when the moving object falls on the retina (Johansson, 1975; Borst, & Egelhaaf, 1989). Then, the signal is transmitted to the relevant areas in the brain. In this process, eye movements play a major role (Hess, et. al., 2007). Only with the movement of the eyes can the environment be scanned, and stimuli can be detected. It is critical in the perception process with the tracking ability of the eyes (Spering, & Gegenfurtner, 2007). This is called smooth pursuit eye movement. Although the role of eye movements is important in the perception of movement, tracking with the eye does not result in movement perception (Tavassoli, & Ringach, 2010; Spering, & Gegenfurtner, 2008). Although

motion perception and smooth pursuit eye movements have many similarities, they are different from each other. Smooth pursuit eye movement provides information for motion perception, but motion perception is not entirely dependent on eye movements (Schütz, Braun, & Gegenfurtner, 2011; Spering & Montagnini, 2010). In addition, studies show that visual motion perception changes according to whether it is for perception or for movement of the agents (Spering, Pomplun, & Carrasco, 2011).

Although there are many factors affecting the perception of motion, the most important one is the direction of motion. In the environment, we are exposed to objects which change their directions constantly. These direction changes also give out biologically important information. For example, a directional change of objects could be caused by a collision, or a directional change of a living being could carry semantic information such as hand gestures. Studies have shown that velocity is the most fundamental variable affecting motion perception, and it has been proven that MT neurons are sensitive to velocity change (Huk, & Heeger, 2000). Studies also show that the direction of motion is determined after a certain threshold, and this threshold differs between individuals (Graham, 1985; Newsome, & Pare, 1988). Thus, not all the directional changes could be perceived by humans. This could be explained due to the fact that a larger directional change would include more information about the state of the object. Moreover, combined directional change of smaller objects could inform us about the general shape of a bigger one. This perception of several moving objects creates a unified perception of motion is directed at a certain angle. Thus, our understanding of motion relies on the integrity of smaller moving parts. For example, a set of birds flying at the same trajectory could be perceived as one larger object in the same direction.

In this aspect, randomly generated and unequally spaced dots in a moving order were used to understand the human motion perception. These computer-generated dots are generally called random dot cinematograms (RDCs) which have signal and noise parts (Braddick, 1974; Grillini, et. al., 2021; Burr & Thompson, 2011; Burns, & Zanker, 1999; Nakayama, 1985). Signal part refers to the dots moving in the same direction and the noise part refers to the dots moving in random direction regardless of the signal (Figure 4). When a certain number of the signal dots move in the same angle, the direction of RDC could be observed as more coherent. The ratio between signal and noise dots is called the coherence level of the cinematogram. Studies show that, with larger coherence levels the motion of the entire stimulus is perceived more correctly. With lower coherence levels, perception of motion direction could be entirely lost. In this aspect, a threshold for detecting motion direction could be established in different experimental conditions. It has been found that humans could detect as low as 5% coherence level (Scase, et. al., 1996). Random dot motion (RDM) is one of the standard stimuli used to understand how motion is processed in the brain and perceptual decision making (van Maanen, et. al., 2012). Commonly used RDM stimuli consist of dots acting at different coherence levels. Thus, speed and direction information can be manipulated (Pilly, & Seitz, 2009; Niwa, & Ditterich, 2008). At the same time, the difficulty of the task changes depending on the coherence level. This is also related to task performance (Britten, et. al., 1992). Random dot motion (RDM) is often used to decide between more

than two options. This is usually associated with deciding between more than two alternatives in daily life (van Maanen, et. al., 2012).

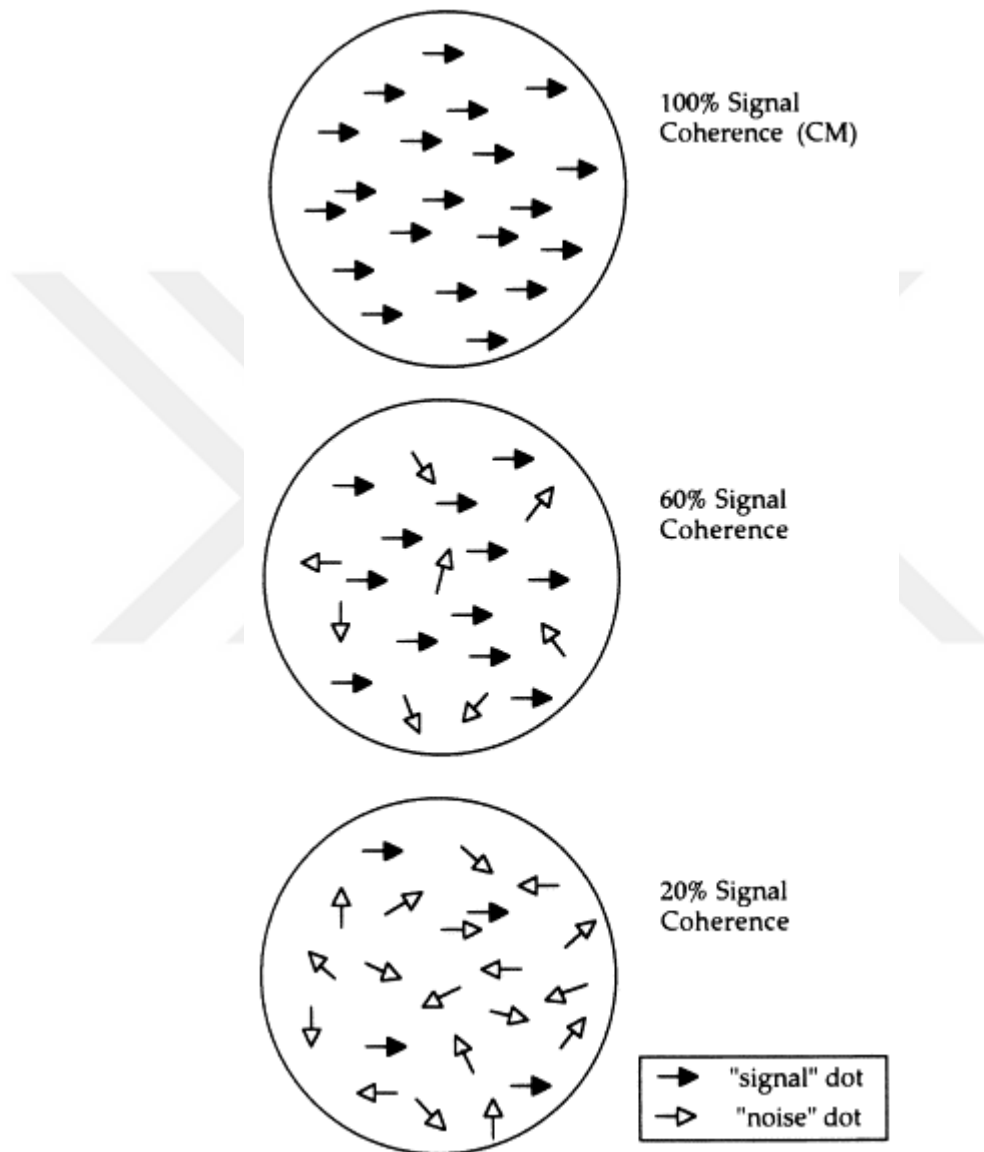


Figure 4: Random Dot Cinematogram (RDC) (Barton, et., al., 1996)

Neural correlates of coherence threshold have been shown in studies with non-human primates. Celebrini and Newsome (1994) recorded single cells from the MT and

MST area of the monkey brain. They found that neural thresholds for direction selective neurons were correlated with the behavioral threshold. This result could be interpreted as a direct link between neural representation of direction with the behavior (Parker & Newsome, 1998). Studies show that the speed of motion and the positions of the stimuli are processed in different places in the brain (Derrington, Allen, & Delicato, 2004; Sheliga, et. al., 2005). Studies with non-human primates show that some of the MT neurons are sensitive to the speed gradients of random dots moving in the same direction (Treue, & Andersen, 1996). At the same time, there are studies showing that eye movements are also important in understanding the speed of motion (Engel, Anderson, & Soechting, 1999; Turano, & Heidenreich, 1999). However, there is a difference between the motion information received from the eye and the motion perceived. In a study conducted with monkeys, it was observed that motion perception and smooth eye movements were processed in MT and ST areas (Newsome, et. al., 1989; Komatsu, & Wurtz, 1989). Similar results are seen in areas that coincide with the same regions in humans (Heeger, & Gandhi, 2001; Robinson, 1965). Studies show that as the coherence level increases, the speed and direction of movement are detected faster (Narasimhan, and Giaschi, 2012; Stone, & Krauzlis, 2003; Gegenfurtner, Xing, Scott, & Hawken, 2003). At the same time, other variables that affect the perception of motion are the density and the size of the dots. However, different results have been obtained in the different studies conducted. For example, in one study, it was concluded that it was easier for people to detect motion as the density increased (Barlow, & Tripathy, 1997) although there are studies showing that density has no effect on the detection of motion and performance (Welchman, & Harris, 2000).

1.4. Perceptual Decision Making

In daily life, people always decide among more than one option. For this reason, decision making has been one of the main study subjects of many scientific fields, from psychology to economics, from statistics to neuroscience. At the same time, it is a matter of curiosity how the decision-making process takes place in the brain (Kim, & Shadlen, 1999; Shadlen, & Kiani, 2013).

1.4.1 Neural Correlates of Perceptual Decision Making

Studies have shown that prefrontal cortex activation is high in high-level cognitive functions such as decision making (Rahnev, et. al., 2016; Fleming, Huijgen, & Dolan, 2012). Perceptual decision making implies how animals detect external stimuli, distinguish them from other stimuli, and categorize them through cognitive and neural processes (Hanks, and Summerfield, 2017; Roitman, & Shadlen, 2002; Heekeren et. al., 2004). As a result of studies conducted with non-human primates, it has been observed that activation in the parietal and dorsal prefrontal cortex in the brain is associated with perceptual decision making (Gold, & Shadlen, 2007). In another study, it was observed that ventral temporal cortex activation in humans was more sensitive to the face than to the houses. This shows that different neuron groups in different regions of the brain are activated in different decision-making processes (Kanwisher, McDermott, & Chun, 1997; Epstein, & Kanwisher, 1998). Shadlen et. al., (1996) found that different perceptual

decisions are formed by the activation of different groups of neurons in the brain. This shows that neurons are specialized for different decisions and have different activation rates.

1.4.2. Motion Based Perceptual Decision Making

The visual motion perception study with monkeys, they were asked to determine in which direction random moving dots with different coherence levels were moving. As a result, it was seen that some neurons were activated when detecting upward motion, while some neurons were activated when detecting downward motion (Shadlen, & Newsome, 2001; Ditterich, Mazurek, & Shadlen, 2003). In another study, Gold and Shadlen (2007) examined the performance of monkeys in detecting the direction of randomly moving dots in motion discrimination task and found strong activation in the lateral intraparietal cortex (LIP).

In decision-making studies, it has been observed that eye movements also influence the process. For example, a study found that eye movements help evaluate different alternatives and monitor decision making (Glaholt, & Reingold, 2011; Yildirim, & Cornelissen, 2015). Similarly, in another study, eye movements were found to be effective in evaluating options. This is the direct contribution of eye movements to the decision-making process (Shimojo, et. al., 2003).

1.4. Perceptual Confidence

Another variable that affects the perception process is people's subjective confidence. It is known that perceptual confidence is associated with prefrontal activation. In addition, high perceptual confidence has a positive effect on control of cognitive functions (Koizumi, Maniscalco, & Lau, 2015). There are studies showing that perceptual confidence is related to perceptual accuracy (Lau, & Passingham, 2006; Rounis, et.al., 2010). There are also studies showing that subjective confidence is associated with prefrontal activity (Lau, & Passingham, 2006). This shows that decision making, which is one of the higher-level cognitive functions, and perceptual confidence may be related to each other. It is also known that prefrontal cortex activation has a critical role in the conscious decision-making process and has an important role in cognitive control (Fleming, Huijgen & Dolan, 2012).

Based on previous studies, the aim of this study is to examine perception of visual motion and decision-making processes. In addition, the effect of perceptual confidence on decision making and motion perception is also examined.

The first of the hypotheses of this study is that motion tracking performances of individuals were expected to decrease in low signal to noise ratio trials. At the same time, low motion tracking performances were expected to have low hit rates.

Secondly, it means that the motion tracking performances of the participants were higher in high signal to noise ratio conditions, which indicates that many of the dots move in the same direction, the joystick strains of the subjects would be higher. At the

same time, it was not expected that the performance of individuals would increase continuously depending on the decrease in the signal to noise ratio.

Thirdly, it was expected that the joystick strains would increase depending on the increase in the hit rates of the participants.

Finally, it was expected that people would make more fixation breaks in trials with low signal to noise ratio. In addition, it was expected that the fixation break numbers of people would decrease as the performance increases and cumulatively depending on the increase in the score.

2.METHOD

2.1. Participants

Twenty-four participants, 12 females and 12 males, participated in this study. Participants were between the ages of 20 and 28 ($M = 23.79$, $SD = 2.57$). Two of the participants were left-handed and the rest were right-handed. Participants did not use glasses or contact lenses during the study. Research was approved by the Science-Ethics Committee of Yeditepe University.

2.2. Experimental Setup

Participants attended in this experiment in the test room called Psycho3 in Cognitive Neuroscience Laboratory at German Primate Center, Georg-August University, Göttingen (see figure 5A). They sat on a height adjustable chair at a distance of 58 cm from a BenQ XL2720T monitor set to a resolution of 1920×1080 and a refresh rate of 60 Hz.

This work was coded through an open-source software called MWorks which was widely used in psychophysics studies with non-human primates. The tasks used in the study were managed via iMac (2010) (see figure 5C) and the stimulus display was done via the MWorks server and iMac Pro (2017) (see figure 5D).

In the study, the participants completed the task by using the joystick (see figure 5B). There was an external battery for the joystick, and it was connected via USB. The forehead rest with a chin cup was used to keep participants' heads stable and to determine the standard of their distance from the screen (see figure 5A). Finally, an EyeLink 1000 (1000 Hz) eye tracker was used to track the eye movements of the participants. Except for the reaction time task in the pretest part of the study, the eye movements of the subjects were recorded (for camera, see Figure 5A, for computing monitor, see Figure 5D).

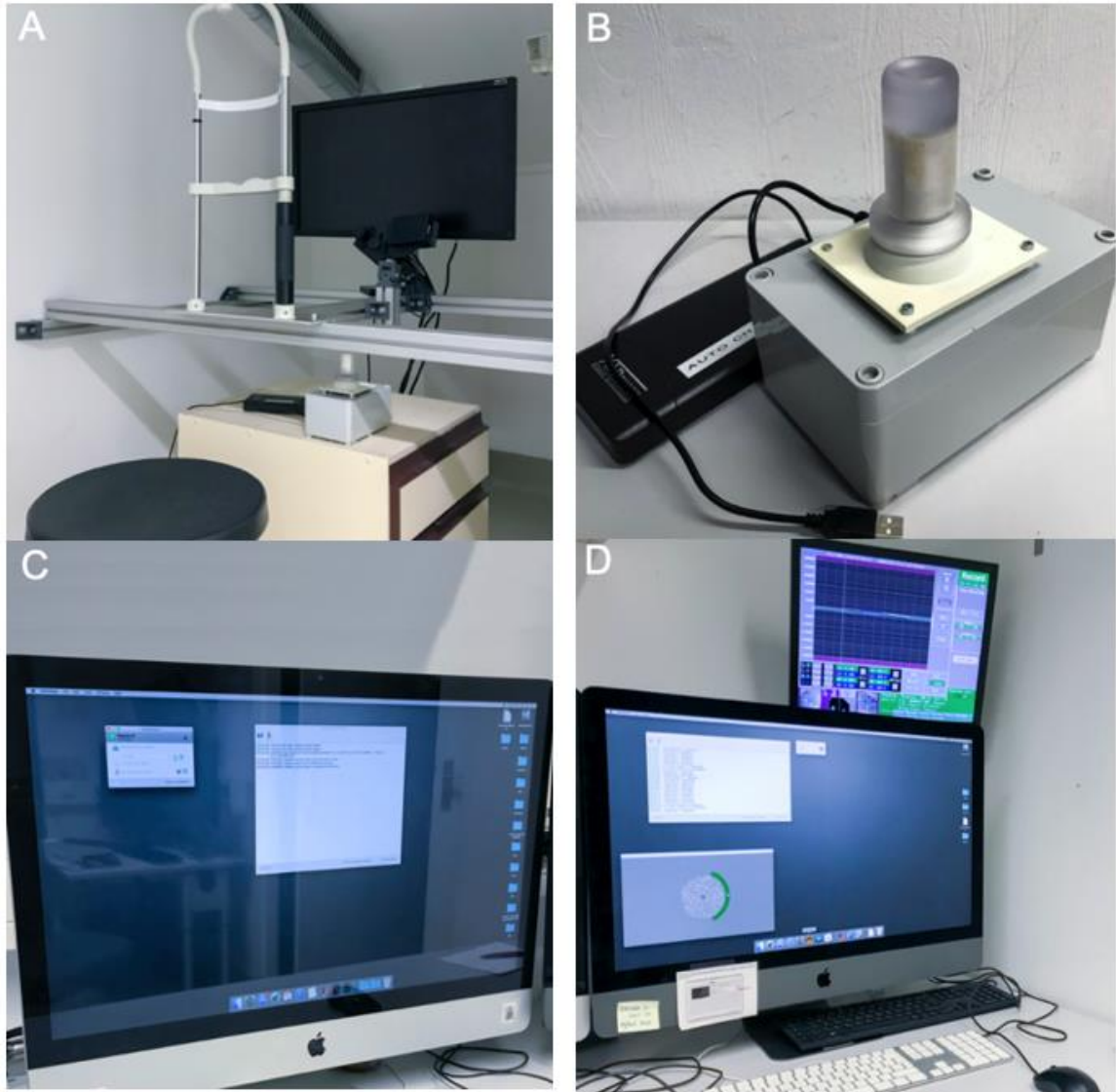


Figure 5: Experimental setup. (A) The test room. (B) The joystick. (C) The tasks managed with it. (D) The tasks displayed for researchers with it.

2.3. Visual Stimuli

Before starting the main experiment, we conducted an SNR pretest and RT task. The stimuli used for pre-test RT consisted of a gray circle in the center on a gray

background, a white dot indicating a joystick cursor in the gray circle, and a black circle which was a target that appeared randomly around the gray circle. The radius of stimulus was 3 degrees of visual angle (dva) for the gray circle, 1 for white dot and 4 black target dots.

In the pre-test SNR and the continuous perceptual report task (CPR), a random dot pattern (RDP) with dynamic noise were used. The radius of the RDP was 8 dva, the velocity of white dots was 4 degrees, and the target's size, which was a transparent dot, was 2 dva. At the same time, the continuous perceptual report task (CPR) had a fixation cross with a size of 3 dva in the middle of the screen and the CPR task had an arc with a size of 3 dva which was located around the central fixation point. The arc size changed depending on joystick movement.

2.4. Experimental Tasks

Before starting the experiment, written consent was obtained from the participants, stating that they voluntarily participated in the study (see Appendix A). In addition, a written information document form describing the experiment process was given to the participants (see Appendix B). Before the main experiment, participants followed several steps. First step was the preparation of the experiment. In this step, calibrations were done using 4 different eccentricity levels. They were 100, 8, 5, and 2 degrees of visual angles. In this process, participants followed a small white dot with their eyes nine times. After calibration, two pretests, which were pretest Reaction Time

and pretest Signal to Noise Ratio which was called Signal to Noise Ratio Task were performed to understand participant's own reaction time and detection threshold for motion direction. At the end of pretests, participants attended the Continuous Perceptual Report Task (CPR). With this task, participants were expected to detect the direction of the random dots moving continuously and to hit the target that appeared accordingly. Thus, it has been tried to understand how participants perceived the motion and how they decided accordingly. The CPR Task took an average of 25 minutes in total. This task consisted of 5 blocks and every block continued for 5 minutes depending on participants reaction time. The calibration phase and 2 pretests and the CPR Task took an hour depending on participants.

2.4.1. Pre-Test Signal to the Noise Ratio (SNR) Task

Before starting the main experiment, two different pretests were performed to understand every participant's threshold to detect motion direction and their reaction times using a joystick. In the SNR pretest, RDP motion was randomly performed during 1000 ms with white fixation cross (see Figure 6A). Afterwards, 4 different possible directions were presented on the screen (4AFC). There were 4 possible random options for each trial. There were different alternatives so that the 2 options were always perpendicular to each other (see Figure 6B and 6C). The reason why different alternatives were used randomly for each trial was to eliminate the learning effect of individuals. At the same time, participants were asked to follow the RDP direction and accordingly

choose the appropriate option for each trial. Participants decided depending on previous RDP direction and reacted using a joystick (see Figure 6D).

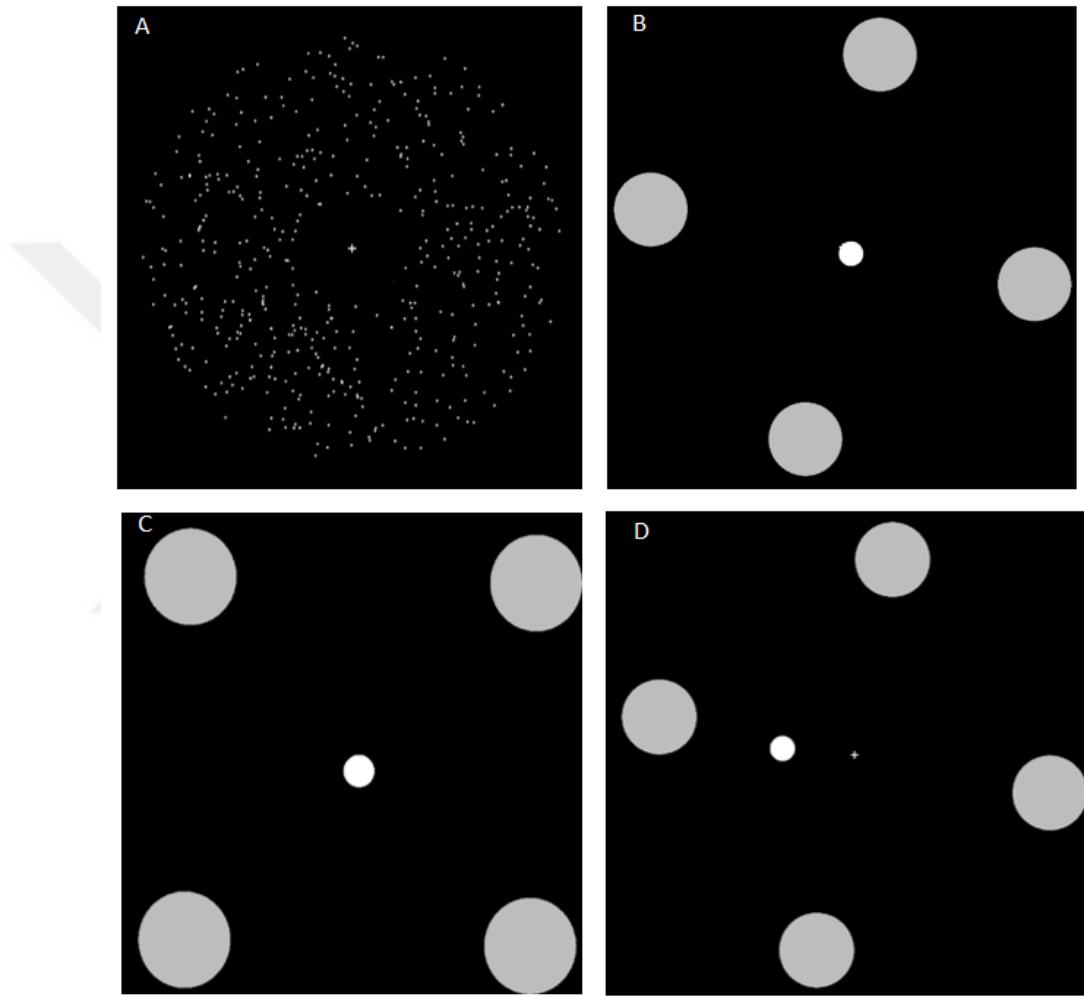


Figure 6: Pre-test SNR Task. (A) Randomly RDP motion with central fixation cross. (B and C) 4 alternative options for different patterns. (D) Correct choice of direction based on previous RDP.

2.4.2 Pre-Test Reaction Time Measurement

In a second pretest, firstly a white dot appeared in the gray circle on the screen (see Figure 7A). After that, a gray big target dot was shown (see Figure 7B) and participants hit the target using a joystick (see Figure 7C). Since each participant's individual reaction time was different, the purpose of this task was to determine the individual's own reaction time. At the same time, since the participants were not familiar with the joystick used for the experiment, they practiced the use of the joystick.

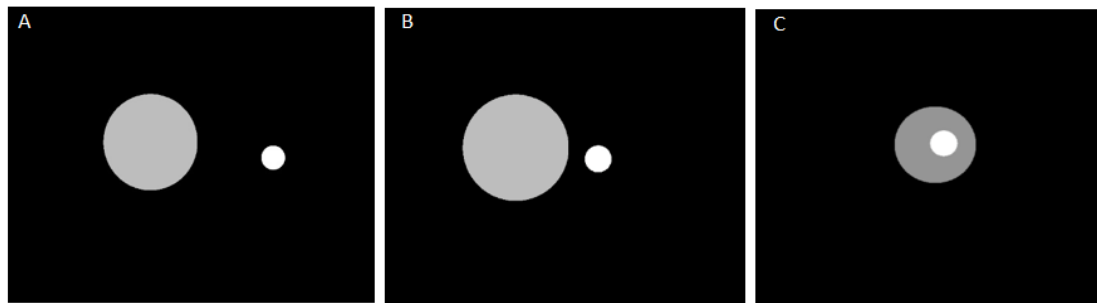


Figure 7: Pre-Test Reaction Time Task. (A) White cursor dot in gray circle (initial phase). (B) Gray target dot appears (C) Hitting the target using the joystick.

2.4.3. Continuous Perceptual Report (CPR) Task

Before the main experiment, it was important that subjects sat in a comfortable position, as eye movements of subjects were recorded throughout the entire experiment. Subjects also placed their chin in a comfortable position on the chinrest and remained stationary throughout the experiment. In cases where people needed to move, re-calibration of the eye was performed, and the experiment remained. In the main

experiment, participants were first asked to start the experiment by moving their joystick in a random direction and focused on the (+) shaped fixation point in the middle. Then they were asked to move the joystick continuously according to the direction of the random dots (see Figure 8A). At the same time, they needed to hit the white coin (target), which appeared as a random dot. For this reason, it was important for people to move their joysticks continuously. The rewards of the participants varied depending on how many targets they hit and the joystick strains during the hit.

Participants' scores varied depending on how many targets they hit. There were 400 targets in total in the study. As a second variable, the arc size which was red and c-shaped, also affected their scores. The size of the arc changed according to the joystick strains of the subjects (see Figure 8B). If participants hit the target with a smaller arc, they got more points. However, the target appeared at different intervals according to the direction of the random dots. The white target coin appeared randomly, and the target was hit with the joystick (see Figure 8C). If the direction of the moving dots could not be detected or if the random dots were not followed continuously, the target was missed (see Figure 8D).

The coherence level of random dots was changing. Six different coherence levels were used in this study: 0, 0.10, 0.16, 0.28, 0.47 and 0.80. Zero coherence level meant all dots move randomly. Therefore, it depended on the chance for subjects to hit the target in the trials with zero coherence level.

Participants should have focused on the central fixation point throughout the experiment. When there was a fixation break, the red fixation point changed to white and

changed in size. At the same time, subjects were given a 10 ms penalty and their arc disappeared at that time.

From the outer circles, the gray one indicated the trial time, and the red circle indicated the gained score. While the red circle grew and circularized according to the target hit and the size of the arc when it was hit, the gray circle ended by decreasing according to the time.

When the target was hit, auditory feedback, which was a high frequency buzzing sound, was given for the reward and at the same time a red circle was formed around the white fixation point. If subjects hit the target with higher joystick strain, the sound was given for the award changes. This task varied according to the speed of the participants and took an average of 20 minutes. Participants could take a break between each block. However, if they moved their head from the chinrest, their eyes were recalibrated, and the next block was started.

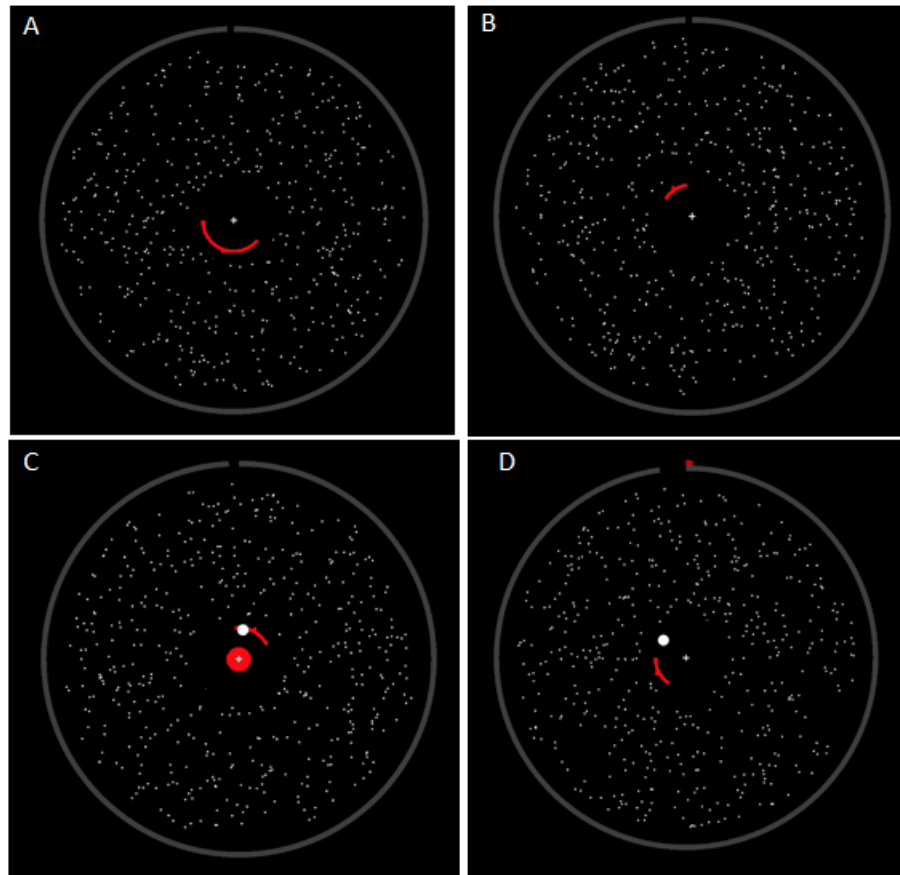


Figure 8: CPR Task. (A) Following RDP with the joystick. (B) Higher joystick strain which indicates smaller arc size. (C) White target coin appears and hits with a joystick. (D) Target miss trial.

2.5. Statistical Analyses

The data collected using MWorks and analysis was performed with Matlab 2019b. A multivariate analysis of variance (MANOVA) has been conducted with coherence level and trial number as independent variables, joystick accuracy, joystick strain and fixation break as dependent variables. The purpose of this analysis was to understand how the joystick strain and accuracy of participants changed depending on the

coherence levels. In addition, it was aimed to understand how the eye movements of participants changed depending on the coherence level by looking at the fixation breaks.

Mean joystick strain at the last 300ms of each steady state was used. Accuracy was measured by normalizing the circular distance between RDP direction and joystick direction into the scale from 0 to 1 (see Appendix C).

Secondly, we conducted Tukey post-hoc tests to understand the relationship between each level of the dependent variable on the independent variables (see Appendix E). Mean differences ($M_{\text{difference}}$) and standard deviation differences ($SD_{\text{difference}}$) were calculated by subtracting the last mentioned coherence level condition from the first mentioned coherence level condition. The mean differences were reported instead of means to show the significant relations between the coherence level conditions.

After that a psychometric logistic function was fitted to the true response data to investigate the coherence level converged when successfully determining the direction of the motion.

Finally, pairwise T-tests were conducted to understand the performance change in the half and second half of the experiment. Mean differences and standard deviation differences were calculated by subtracting the last mentioned condition from the first mentioned condition.

3.RESULTS

3.1. Multivariate Statistical Tests of Variance

Multivariate tests showed that there was a significant effect of coherence level on joystick accuracy, joystick strain and fixation break combined ($F(20, 12816) = 15.237$, $p < .0005$; Wilk's $\Lambda = .935$, partial $\eta^2 = .019$). There was a significant effect of trial number on joystick accuracy, joystick strain, reward and fixation break combined ($F(20, 15468) = 180.856$, $p < .0005$; Wilk's $\Lambda = .438$, partial $\eta^2 = .186$). There was a significant interaction effect of coherence level and trial number on joystick accuracy, joystick strain and fixation break combined ($F(96, 15309) = 2.955$, $p < .0005$; Wilk's $\Lambda = .930$, partial $\eta^2 = .018$).

Multiple ANOVAs were conducted to investigate the relationship between every independent variable and every dependent variable (see Appendix D).

Coherence level significantly affected the strain ($F(5) = 35.058$, $p < .0005$), accuracy ($F(5) = 24.750$, $p < .0005$), and reward ($F(5) = 4.101$, $p = .001$), but did not significantly affect the fixation breaks ($p > .05$) (Figure 9).

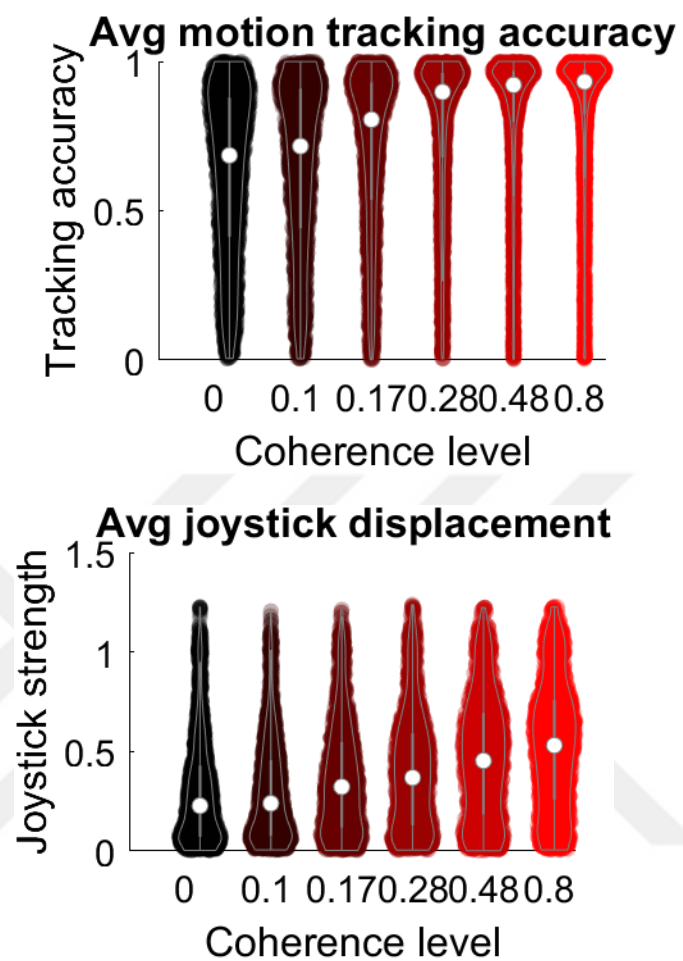


Figure 9: Motion Tracking Accuracy (top) and Strain (bottom)

Trial number significantly affected fixation breaks ($F(5) = 6.456, p < .0005$) and reward ($F(5) = 742.480, p < .0005$), but did not significantly affect the strain ($p > .05$) and the accuracy ($p > .05$) (Figure 10).

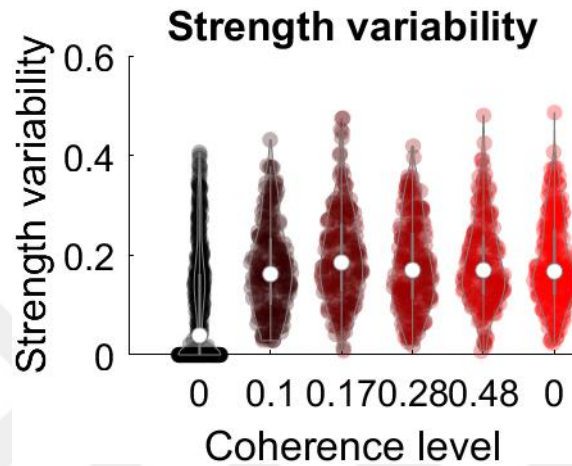


Figure 10: Average joystick strain.

The interaction effect of coherence level and trial number was significant on strain ($F(24) = 3.241, p < .0005$), accuracy ($F(24) = 1.763, p < .012$), fixation number ($F(24) = 2.317, p < .0005$), and reward ($F(24) = 4.748, p < .0005$).

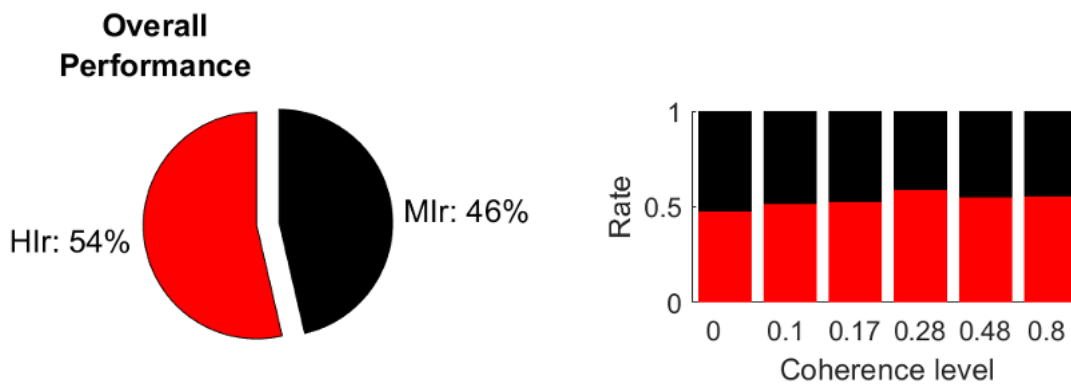


Figure 11: Hit and miss rates

3.1.1. Post-Hoc Tests

Post-hoc tests of strain on each coherence level showed that, strain was significantly lower on 0 coherence condition than 0.1 ($M_{\text{difference}} = -.045$, $SD_{\text{difference}} = .015$, $p = .037$), 0.16, ($M_{\text{difference}} = -.096$, $SD_{\text{difference}} = .015$, $p < .000$), 0.28 ($M_{\text{difference}} = -.117$, $SD_{\text{difference}} = .014$, $p < .000$), 0.47 ($M_{\text{difference}} = -.193$, $SD_{\text{difference}} = .015$, $p < .000$), and 0.8 ($M_{\text{difference}} = -.220$, $SD_{\text{difference}} = .014$, $p < .000$). Strain was significantly lower on 0.1 coherence condition than 0.16, ($M_{\text{difference}} = -.051$, $SD_{\text{difference}} = .015$, $p = .11$), 0.28 ($M_{\text{difference}} = -.071$, $SD_{\text{difference}} = .014$, $p < .000$), 0.47 ($M_{\text{difference}} = -.148$, $SD_{\text{difference}} = .014$, $p < .000$), and 0.8 ($M_{\text{difference}} = -.175$, $SD_{\text{difference}} = .014$, $p < .000$). Strain was significantly lower on 0.16 coherence condition than 0.47 ($M_{\text{difference}} = -.096$, $SD_{\text{difference}} = .015$, $p < .000$), and 0.8 ($M_{\text{difference}} = -.123$, $SD_{\text{difference}} = .014$, $p < .000$). Strain was significantly lower on 0.28 coherence condition than 0.47 ($M_{\text{difference}} = -.076$, $SD_{\text{difference}} = .014$, $p < .000$), and 0.8 ($M_{\text{difference}} = -.103$, $SD_{\text{difference}} = .013$, $p < .000$). Tukey criterion post-hoc tests did not reveal a significant difference of strain between 0.47 and 0.8 coherence conditions. Mean difference and standard deviation differences were calculated by subtracting the last mentioned coherence level condition from the first mentioned coherence level condition

Accuracy was significantly lower on 0 coherence condition than 0.28 ($M_{\text{difference}} = -.0016$, $SD_{\text{difference}} = .0001$, $p < .000$), 0.47 ($M_{\text{difference}} = -.0021$, $SD_{\text{difference}} = .0001$, $p < .000$), and 0.8 ($M_{\text{difference}} = -.002$, $SD_{\text{difference}} = .0001$, $p < .000$). Accuracy was significantly lower on 0.1 coherence condition than 0.28 ($M_{\text{difference}} = -.001$, $SD_{\text{difference}} = .0001$, $p < .000$), 0.47 ($M_{\text{difference}} = -.001$, $SD_{\text{difference}} = .0002$, $p < .000$), and 0.8 ($M_{\text{difference}} = -.001$, $SD_{\text{difference}} = .0001$, $p < .000$). Accuracy was significantly lower on 0.16 coherence condition than 0.28

($M_{\text{difference}} = -.001$, $SD_{\text{difference}} = .0001$, $p < .000$), 0.47 ($M_{\text{difference}} = -.001$, $SD_{\text{difference}} = .0001$, $p < .000$), and 0.8 ($M_{\text{difference}} = -.001$, $SD_{\text{difference}} = .0001$, $p < .000$).

3.2. Psychometric Function

A logistic function was fitted to the accuracy of responses on different coherence levels. Brute-force search revealed alpha value of 0.1, and beta value of 5.01.

Bootstrapping with 400 repetitions revealed standard deviation (SD) of alpha to be 0 and SD of beta to be 0.3. (Figure 12)

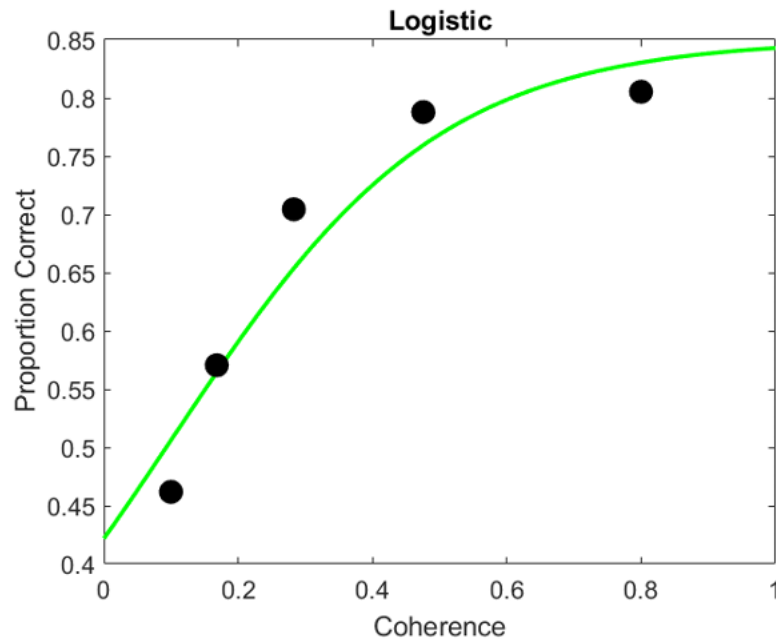


Figure 12: Psychometric function fitted to the joystick accuracy.

3.3. Pairwise T-Tests

Pairwise T-tests were applied between the first half and the last half of the experiment to see if there is a significant difference in the performance. There was no significant difference of strain ($M_{\text{difference}}=-0.023$, $SD_{\text{difference}}=0.021$, $p>.05$) and accuracy ($M_{\text{difference}}=0.017$, $SD_{\text{difference}}=0.023$, $p>.05$) between the first half and the second half of the experiment (Figure 13).

Pairwise T-tests were applied to the mean strain between before the reward and after the reward. There was a significant difference on strain between before the reward and after the reward ($M_{\text{difference}}=0.164$, $SD_{\text{difference}}=0.042$, $p<0.005$).

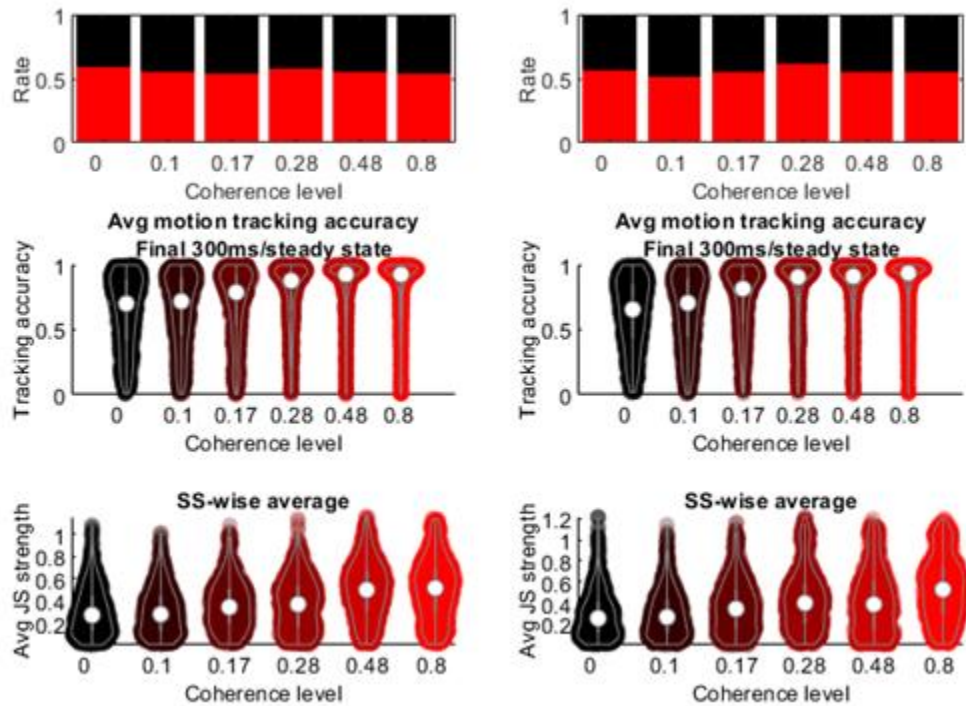


Figure 13: Hit rate (top), accuracy (middle), strain (bottom) of first half (left) and last half (right) of the experiment.

4.DISCUSSION

The purpose of this study is to examine how motion tracking performances of individuals change according to different coherence levels. Accordingly, the motion tracking performance of individuals was investigated. At the same time, it has been examined how the perceptual confidence of people affects their perception of visual motion and decision-making processes.

4.1. Motion Tracking Performance

In this study, the motion tracking performance of the subjects was evaluated according to the signal to noise ratio. Accordingly, motion tracking performance can be explained by looking at the rate of hitting and missing targets that participants see during the CPR task. At the same time, since subjects must continuously follow the motion of the dots with the joystick, the joystick strains - which are the force they apply to the joystick- and the accuracy of the joystick -which indicates the direction of the joystick complying with random dots'- were important. It is examined how the joystick strain, joystick accuracy and target hit rates change depending on the coherence level, that is, the signal to noise ratio.

According to previous studies, the motion tracking performance of participants increased in the higher coherence level (Borst, & Egelhaaf, 1989; Barlow, & Tripathy, 1997; Narasimhan, & Giaschi, 2012). Accordingly, hit rate of participants decreased in trials with low signal to noise ratio. Studies using a random dot cinematogram show that

motion detection performance varies depending on the coherence level. According to the signal to noise ratio used in previous studies, the motion sensitivity of the individuals varies, and they have found the range in which the noise is noticeable as 0.5-2.5% (Burns, & Zanker, 1999). In a study, participants' thresholds for noticing the motion called just noticeable difference were investigated. According to the results found, the threshold for noticing the motion of the people varies according to the signal to noise ratio, which is called the stimulus intensity (Zanker, 1995). As a result of my study, it has been found that joystick accuracy changed depending on signal to noise ratio in a non-linear trend. As the signal to noise ratio increased, the motion tracking performance of the subjects also increased. Individuals' performance tended to increase at coherence levels of 0, 0.10, 0.16, and 0.28. However, there was no significant difference between the joystick accuracy of participants between 0.47 and 0.80 ratios. This shows that people have a threshold while detecting the direction of motion and the motion tracking performance does not increase linearly. At the same time, joystick strains of the individuals did not change between the 0.47 and 0.80 coherence levels

Studies also show that motion tracking and motion direction detection performances of individuals vary according to signal to noise ratio (Narasimhan, & Giaschi, 2012; Kaneko, & Murakami, 2009; Albright, & Stoner, 1995). It was seen that the task performance of the individuals changed depending on the signal to noise ratio. In different coherence levels, the motion tracking performance of participants was evaluated. As a result of the study, a relationship was observed between the joystick accuracy of the individuals and the coherence level of the stimulus. The fact that participants move their joysticks in the same or close to the direction that random dots are

moving is related to detection of the direction of motion. Thus, the results are consistent with previous studies, and it was found that the motion tracking performance of individuals changed according to the signal to noise ratio.

4.2. Perceptual Confidence

Joystick strain can also be associated with perceptual confidence as participants apply more force when they think the motion direction is assessed profoundly. It was expected that the perceptual confidence would change during motion tracking according to the signal to noise ratio (Scase, et. al., 1996; van Maanen, et. al., 2012; Lau, & Passingham, 2006; Rounis, et.al., 2010). Also, it proves the non-linear nature of the perceptual confidence in motion perception by complying with the signal detection theory (Parker, & Newsome, 1988; Gescheider, 1977; Green, & Swets, 1966; Janssen, & Shadlen, 2005). This also shows that people have a threshold of coherence in detecting the direction of motion. In this aspect, it can be said that signal detection theory and threshold theory in psychophysics applies to the motion tracking performance and most prominently it applies to the perceptual confidence (Stanislaw, & Todorov, 1999; Palmer, Huk, & Shadlen, 2005). Thus, it was expected that the joystick strain applied by people would be more in high SNR trials, where people could detect the direction of motion more easily and quickly. However, it was observed that there was no linear increase, and the perceptual confidence of the individuals did not change after the 0.47 SNR rate. This shows that the perceptual confidence changes depending on the SNR but is fixed at a certain threshold.

It is also possible to evaluate the perceptual confidence of individuals by looking at the target hit and target missing rates in trials with different SNRs. However, wrong conclusions could be drawn when it is evaluated only with whether the target is hit or not. Thus, in this study, I evaluated the performance of individuals according to two different variables. The first of these is target hit and the second one is the joystick strain, as reward was calculated and presented to the participants according to the combination of these two variables. I concluded that the strategies that people use throughout the task were related to perceptual confidence. For example, there are small differences between the hit counts of participants in all coherence levels. However, the joystick strain applied by subject differs depending on SNR. I could explain this as the fact that hit rates in high SNR trials do not differ much compared to low SNR trials, as the strategies used by participants change. The increase in the strain applied by individuals in high SNR trials was seen with the small arc size. This reduces the possibility of hitting the target. Thus, even if individuals detected the direction of the motion correctly and their joystick accuracy was high, it may result in not being able to hit the target due to the strategies they choose. Similarly, although it was difficult to determine the direction of movement in low SNR trials, the target hit rates of individuals were approximately %50. This is because subjects had a large arc size due to the low strain of the joystick they apply. Thus, it increases the probability of people hitting the target that appears randomly. This indicated that different strategies had been used by individuals in assessing motion perception. Low SNR and high SNR conditions would create diverse tendencies towards the choice of the strategy in detection of motion direction.

Finally, the relationship between the reward earned by the individuals and the joystick strain and joystick accuracy was examined. The rewards of the subjects depend on the rate of hitting the target and the joystick strain, i.e., arc size, when the target hits. When the participants hit the target, there was auditory feedback. However, if the joystick strain was high after a hit, a different tone of audible feedback was given. In addition, it was investigated whether there was a relationship between joystick strain and joystick accuracy after the cumulative increased in rewards. However, no statistically significant result was obtained. Then, after each reward, the change in joystick strain and joystick accuracy was examined. As a result, a significant relationship was observed between reward and joystick strain and joystick accuracy. Depending on the coherence level, reward was significantly different. This indicates a similar conclusion with the joystick accuracy but would involve the combined effect of accuracy and strain. This combination would indicate a relationship between these two variables in motion perception.

4.3. Perceptual Learning

Studies show that while people perceive the direction of motion, their direction discrimination performance improves with practice. However, it was observed that this performance improvement was seen in the directions specifically practiced and this development could not be adapted to new directions (Liu, 1999). Although the performance of individuals in detecting the direction of motion improves depending on their practice time, this development is associated with task difficulty. As the task gets harder, people need more practice. In addition, there are studies showing that it becomes

more difficult for people to identify a different direction from the way they learn (Karni, 1996; Ahissar, & Hochstein, 1997). In their study, Liang and his colleagues (2015) divided people into two groups and trained a group for the direction discrimination task. The other group did not train as a control condition. As a result of the study, they showed that the direction discrimination task performance of the people in the practice group was not higher than the people in the untrained condition. In addition to these, there are studies showing that the reward mechanism also increases the effect on perceptual learning (Fahle, 2004).

Based on all these results, a task consisting of 6 blocks was designed in this study. After that, the performances of the individuals in each block were evaluated separately. However, no performance difference was observed between the blocks. This shows that the joystick accuracy and joystick strains did not change between the blocks. Thus, the performance of participants did not change with getting used to the task and their motion tracking performance depended on different variables. It is important to see the performance between blocks does not change, in order to effectively evaluate other variables that may have an effect on performance. In addition, the first half of the experiment has been compared to the second half of the experiment on joystick strain and joystick accuracy. However, there was no significant difference between the first half of the experiment and the second half. This, unlike other studies, has nothing to do with the performance of individuals that can be explained by practice.

4.4. Fixation Breaks

Studies show that eye movements are important for motion tracking. For this reason, many studies have been conducted examining the relationship between eye movements and visual movement perception (Spering, & Gegenfurtner, 2007; Tavassoli, & Ringach, 2010; Spering, & Gegenfurtner, 2008). There are also studies showing the effects of eye movements on decision making process. Eye movements play a major role in decision-making as a result of evaluating different alternatives (Glaholt, & Reingold, 2011; Shimojo, et. al., 2003). In this study, we investigated that effect of coherence level on fixation break counts.

However, no significant conclusion could be reached regarding the effects of eye movements on decision making and perception of motion process. The central fixation cross was used in the experiment and the subjects were asked to focus on it during the task. In this way, it was aimed to fix the eye movements on central fixation cross. As a result of the study, it was observed that people did not make a fixation break despite their changing task conditions. In this task in which different signal to noise ratios were used, the task performance gets harder and easier. However, it was expected that the fixation breaks of people would increase depending on the difficulty of the task and they would make more fixation breaks in the low signal to noise ratio trials. Since studies in the literature have shown that task difficulty has a facilitating effect on people's eye movements in detecting the direction of motion, more eye movements were expected when it became difficult to detect the direction of motion (Engel, Anderson, & Soething, 2000; Gegenfurtner, Xing, Scott, & Hawken, 2003). One of the most important results of

this study was that fixation breaks do not have a significant effect on detecting direction discrimination in this task with different signal to noise ratios. According to the statistical analyzes, it was seen that the joystick strain and joystick accuracy of the individuals changed depending on the coherence level. However, there was no difference in the fixation break counts of the individuals. In addition, it was investigated whether there was a change in fixation breaks depending on the award they received, and no significant results could be reached. This raises the question of the effect of eye movements on visual motion perception and decision-making processes.

4.5. Limitations

If we continue with the limited aspects of the study, the change in the performance of the individuals can be understood more clearly by using more levels of signal to noise ratio. Especially by increasing the low coherence level rates, the threshold at which people notice the direction of the motion can be better detected. Although the result of the study shows a threshold about how the performances of the people change according to the changing coherence levels, it is necessary to use more coherence levels in order to understand the performance change more clearly. Also, coherence levels could be chosen from a linear scale instead of a logarithmic one in order to see the linear increase in motion tracking performance and perceptual confidence.

In addition, in this study, only the fixation break parameter was evaluated regarding eye movements. For this reason, this study does not give a general result about

how people's eye movements change depending on the coherence level and affect their task performance.

4.6. Future Research

Future research should include a paradigm without a fixating eye. In this aspect, we can investigate the relationship between eye-hand coordination in motion tracking. This would allow individuals to use another strategy with their eyes and this may reveal different mechanisms in understanding visual movement. Secondly, same paradigm could be used in a dyadic setting in order to understand the change of strategies in presence of another agent. This study could reveal the social aspect of motion recognition and visual perception.

4.7. Conclusion

In this study, motion tracking performance and decision-making strategies of individuals were examined. Their task performance varied depending on the gaming strategy used. As a result of the study, it was seen that their task performance and strategy changed depending on the coherence level. It was concluded that, in tracking the motion of objects like cars in the environment, people used different strategies to detect their speed and direction. And the performance of individuals non-linearly increased depending on the signal available on the visual scene. A certain threshold of noise was present in motion detection processes. This may explain the different evaluations of the

same action that people see in daily life. Also, a similar conclusion was possible to be seen about the perceptual confidence of individuals. At the same time, it has been seen that individuals' perceptual confidence has an effect on their understanding and evaluation of the outside world. This can also show that individuals can evaluate the same event differently.



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APPENDIX A.

Consent to the collection and processing of personal data in the context of experimental data collection and related information according to Art. 13 GDPR

Deutsches Primatenzentrum Gesellschaft mit beschränkter Haftung –
Leibniz Institut für Primatenforschung

Controller

Kellnerweg 4, 37077 Göttingen

Address

Cognitive Neuroscience Laboratory (Abteilung Kognitive Neurowissenschaften)

Location/Institution (please enter, if different to responsible person)

Surname, first name

(please enter in block letters)

Date of birth

I hereby consent to the collection and processing of my personal data such as

- First and last name
- Gender
- Date of birth
- Address
- Phone number
- Visual faculty
- Handedness

by the controller .

The controller processes the personal data for the purpose of scientific research collection and analysis and the scientific work resulting from it. Personal data is stored and processed internally only.

I have been informed that I can withdraw my consent at any time. If the consent is not granted, there will be no data processing. If the consent was first granted and subsequently revoked, the data collected up to the revocation will, as far as technically possible, be deleted or restricted for use and no longer be used.

I received the information according to Article 13 of the EU General Data Protection Regulation (GDPR).

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Place, Date

Signature

WWW.S-CON.DE

NAME

Freigabe: Swetlana Herfort

DATUM BEMERKUNG

22.08.2018

Datei/Datum

DPZ_Consent in publikation_F01 Seite 1 von 2

Consent to the collection and processing of personal data in the context of experimental data collection and related information according to Art. 13 GDPR

CONTROLLER OF THE PROCESSING OF YOUR PERSONAL DATA IS:

RESPONSIBLE FOR THE PROCESSING OF YOUR PERSONAL DATA IS:

Deutsches Primatenzentrum Gesellschaft mit beschränkter Haftung – Leibniz Institut für Primatenforschung
Kellnerweg 4
37077 Göttingen

If you have any questions or wish to make contact with our data protection officer you can do this under the following address: datenschutzteam@s-con.de or **S-CON DATENSCHUTZ Kriegerstraße 44 30161 Hannover.**

The personal data transmitted by you is collected, processed and used based on your given consent in accordance with Article 6 Abs. 1 UAbs. 1 lit. a) EU General Data Protection Regulation (GDPR). The personal data will be collected and processed for the purpose of scientific research collection and analysis and the scientific work resulting from it. Unfortunately, we cannot include you in the subject database in the case of non-provisioning of your personal data. An automatic placement does not take place.

A transfer of your personal data to external third parties does not take place.

You also have the right to revoke your consent to the collection and processing of personal data for the above-mentioned purposes. The duration of the storage of personal data of you ends with your express revocation.

A transmission of the personal data you provided to a third country or an international organisation both does not take place and is not planned.

In accordance with Article 15 GDPR you have the right of information about the processing of your personal data.

Furthermore, you are free to claim your rights to correction, deletion or, if deletion is not possible, of limitation of the processing and of data portability in accordance with Article 16-18, 20 GDPR. If you want to take advantage of this right, please refer to our data protection officer.

Furthermore, you have the right to complain at any time to the responsible supervisory authority. If you have the opinion that the processing of your personal data does not take place in compliance with the data protection laws, we kindly ask you to contact our data protection officer.

WWW.S-CON.DE NAME DATUM BEMERKUNG

Freigabe: Swetlana Herfort 22.08.2018

Datei/Datum DPZ_Consent in publikation_F01 Seite 2 von 2

APPENDIX B

Dear Participant,

Thank you very much for participating in our experiment.

Below, you will find an overview of the experimental procedures. Please don't hesitate to ask if you have any questions.

We will perform a series of experiments:

- 1) Eye calibration
- 2) Reaction time measurements
- 3) Estimation of sensitivity to visual motion
- 4) Continuous perceptual report task [main experiment]

The duration of session is about one hour.

Here a short explanation of the experiments:

1. Eye calibration

We are interested in your gaze pattern. Thus, your eye movements will be tracked during the main experiment. To obtain meaningful data, we need to carefully calibrate the eye tracker. This calibration works in the following way:

1. Place your head on the chinrest. Please try not to move your head. It is important for the calibration process.
2. Look at the screen.
3. A white dot will appear at a random location.
4. Look directly at that point until it disappears.
5. This process will repeat several times.

2. Reaction time measurement

We want to analyze your reaction times to make inferences about your task performance in the main experiment. To do so, we want to estimate the time it takes you to react to a target on the screen. Your task is as follows:

1. Place your head on the chinrest. Try not move your head. Look at the screen.
2. Place your dominant hand on the joystick.
3. A white cursor will be present on the screen. You can control it with your joystick movements.
4. A black target will appear at a random location.
5. Move the cursor to the target as fast as you can.

3. Estimation of sensitivity to visual motion

In the main experiment, you will be looking at a moving random dot pattern. To make sense of the data, we need to know how well you can perceive visual motion. To this end, we have designed a simple 4 alternative-forced choice task. This is what you need to do:

1. Place your head on the chin rest. Try not to move your head. Look at the screen.
2. Place your dominant hand on the joystick.
3. A moving random dot pattern will appear on the screen for 1 second. A fraction of these dots will move in the same direction.
4. After the random dot pattern disappears, 4 targets will appear on the screen.
5. Indicate your perceived dot motion direction by moving the cursor to one of the four presented targets.

4. Continuous perceptual report task

The main experiment investigates your real-time decision processes. You will be performing a continuous perceptual report task. Here are your instructions:

1. Place your head on the chin rest. Try not to move your head. Look at the screen.
2. Place your dominant hand on the joystick.
3. You can start a trial by moving the joystick.
4. A fixation cross will be presented at the center of the screen. Please look at this fixation cross.
5. We will present a random dot motion pattern. The stimulus changes motion direction constantly.
6. You can earn money by collecting coins. The motion direction of the stimulus is predictive of where a coin might appear.
7. Use the joystick to indicate the predominant motion direction.
8. Instead of a cursor, you control a colored arc (i.e. partial circle) with the joystick. It indicates the joystick direction and degree of displacement.
9. Collect coin by aligning them with your arc. This is only possible if you look at the central fixation cross. Otherwise, your arc will disappear.
10. With large joystick displacement, the arc becomes narrower, making it harder to collect the targets. However, if you catch a coin with a narrow arc, you will get more reward.
11. You will be paid according to your task performance.

APPENDIX C.

Multivariate Tests^a

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	1,000	22976990,3 ^b	4,000	3864,000	,000	1,000
	Wilks' Lambda	,000	22976990,3 ^b	4,000	3864,000	,000	1,000
	Hotelling's Trace	23785,704	22976990,3 ^b	4,000	3864,000	,000	1,000
	Roy's Largest Root	23785,704	22976990,3 ^b	4,000	3864,000	,000	1,000
Coherence_Level	Pillai's Trace	,076	14,903	20,000	15468,000	,000	,019
	Wilks' Lambda	,925	15,237	20,000	12816,388	,000	,019
	Hotelling's Trace	,080	15,518	20,000	15450,000	,000	,020
	Roy's Largest Root	,071	54,760 ^c	5,000	3867,000	,000	,066
Trial_Number	Pillai's Trace	,564	127,043	20,000	15468,000	,000	,141
	Wilks' Lambda	,438	180,856	20,000	12816,388	,000	,186
	Hotelling's Trace	1,274	246,109	20,000	15450,000	,000	,242
	Roy's Largest Root	1,269	981,695 ^c	5,000	3867,000	,000	,559
Coherence_Level * Trial_Number	Pillai's Trace	,072	2,951	96,000	15468,000	,000	,018
	Wilks' Lambda	,930	2,955	96,000	15309,693	,000	,018
	Hotelling's Trace	,074	2,958	96,000	15450,000	,000	,018
	Roy's Largest Root	,031	4,973 ^c	24,000	3867,000	,000	,030

a. Design: Intercept + Coherence_Level + Trial_Number + Coherence_Level * Trial_Number

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

APPENDIX D

Multiple ANOVAs							
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Strain	29,818 ^a	34	,877	12,515	,000	,099
	Accuracy	,003 ^b	34	9,360E-5	7,921	,000	,065
	Fixation_Break	21,934 ^c	34	,645	3,036	,000	,026
	reward	3496,265 ^d	34	102,831	118,238	,000	,510
Intercept	Strain	137,605	1	137,605	1963,659	,000	,337
	Accuracy	1008,690	1	1008,690	85362543,87	,000	1,000
	Fixation_Break	122,815	1	122,815	577,899	,000	,130
	reward	3754,433	1	3754,433	4316,944	,000	,527
Coherence_Level	Strain	12,283	5	2,457	35,058	,000	,043
	Accuracy	,001	5	,000	24,750	,000	,031
	Fixation_Break	1,874	5	,375	1,764	,117	,002
	reward	17,834	5	3,567	4,101	,001	,005
Trial_Number	Strain	,798	5	,160	2,277	,044	,003
	Accuracy	1,975E-5	5	3,950E-6	,334	,892	,000
	Fixation_Break	6,860	5	1,372	6,456	,000	,008
	reward	3228,662	5	645,732	742,480	,000	,490
Coherence_Level * Trial_Number	Strain	5,452	24	,227	3,241	,000	,020
	Accuracy	,000	24	2,083E-5	1,763	,012	,011
	Fixation_Break	11,819	24	,492	2,317	,000	,014
	reward	99,102	24	4,129	4,748	,000	,029
Error	Strain	270,983	3867	,070			
	Accuracy	,046	3867	1,182E-5			
	Fixation_Break	821,816	3867	,213			
	reward	3363,118	3867	,870			
Total	Strain	851,797	3902				
	Accuracy	3879,975	3902				
	Fixation_Break	1234,000	3902				
	reward	18549,304	3902				
Corrected Total	Strain	300,800	3901				
	Accuracy	,049	3901				
	Fixation_Break	843,750	3901				
	reward	6859,383	3901				

a. R Squared = ,099 (Adjusted R Squared = ,091)

b. R Squared = ,065 (Adjusted R Squared = ,057)

c. R Squared = ,026 (Adjusted R Squared = ,017)

d. R Squared = ,510 (Adjusted R Squared = ,505)

APPENDIX E

Multiple Comparisons

Tukey HSD							
Dependent Variable	(I) Coherence_Level	(J) Coherence_Level	Mean	Std. Error	Sig.	95% Confidence Interval	
			Difference (I-J)			Lower Bound	Upper Bound
Strain	.0000	.1000	-.045350239	.0153203769	.037	-.089030746	-.001669732
		.1682	-.096678948	.0151155429	.000	-.139775445	-.053582451
		.2828	-.117117419	.0145977580	.000	-.158737640	-.075497198
		.4757	-.193470298	.0151092400	.000	-.236548824	-.150391771
		.8000	-.220437654	.0141809638	.000	-.260869537	-.180005770
	.1000	.0000	.045350239	.0153203769	.037	.0016697320	.0890307456
		.1682	-.051328709	.0154112653	.011	-.095268351	-.007389067
		.2828	-.071767180	.0149037578	.000	-.114259849	-.029274512
		.4757	-.148120059	.0154050833	.000	-.192042076	-.104198042
		.8000	-.175087415	.0144957647	.000	-.216416839	-.133757991
	.1682	.0000	.096678948	.0151155429	.000	.0535824506	.1397754445
		.1000	.051328709	.0154112653	.011	.0073890666	.0952683509
		.2828	-.020438472	.0146931170	.733	-.062330574	.0214536308
		.4757	-.096791350	.0152013908	.000	-.140132612	-.053450089
		.8000	-.123758706	.0142791066	.000	-.164470408	-.083047004
	.2828	.0000	.117117419	.0145977580	.000	.0754971985	.1587376399
		.1000	.071767180	.0149037578	.000	.0292745119	.1142598489
		.1682	.0204384717	.0146931170	.733	-.021453631	.0623305742
		.4757	-.076352879	.0146866328	.000	-.118226494	-.034479264
		.8000	-.103320234	.0137298137	.000	-.142465827	-.064174642
	.4757	.0000	.193470298	.0151092400	.000	.1503917715	.2365488244
		.1000	.148120059	.0154050833	.000	.1041980425	.1920420757
		.1682	.096791350	.0152013908	.000	.0534500892	.1401326115
		.2828	.076352879	.0146866328	.000	.0344792636	.1182264938
		.8000	-.026967356	.0142724343	.409	-.067660034	.0137253223
	.8000	.0000	.220437654	.0141809638	.000	.1800057704	.2608695369
		.1000	.175087415	.0144957647	.000	.1337579909	.2164168388
		.1682	.123758706	.0142791066	.000	.0830470044	.1644704078
		.2828	.103320234	.0137298137	.000	.0641746423	.1424658265
		.4757	.0269673557	.0142724343	.409	-.013725322	.0676600338
Accuracy	.0000	.1000	-.000400268	.0001989441	.336	-.000967485	.0001669494
		.1682	-.000656134	.0001962842	.011	-.001215767	-.000096501
		.2828	-.001645986	.0001895605	.000	-.002186449	-.001105523
		.4757	-.002130375	.0001962024	.000	-.002689775	-.001570975
		.8000	-.002044737	.0001841481	.000	-.002569768	-.001519705
	.1000	.0000	.0004002677	.0001989441	.336	-.000166949	.0009674847
		.1682	-.000255866	.0002001243	.797	-.000826448	.0003147158
		.2828	-.001245718	.0001935340	.000	-.001797510	-.000693926
		.4757	-.001730107	.0002000441	.000	-.002300460	-.001159754
		.8000	-.001644469	.0001882360	.000	-.002181156	-.001107782
	.1682	.0000	.000656134	.0001962842	.011	.0000965006	.0012157673
		.1000	.0002558663	.0002001243	.797	-.000314716	.0008264484
		.2828	-.000989852	.0001907988	.000	-.001533845	-.000445858
		.4757	-.001474241	.0001973990	.000	-.002037053	-.000911429
		.8000	-.001388603	.0001854226	.000	-.001917268	-.000859937
	.2828	.0000	.001645986	.0001895605	.000	.0011055225	.0021864485
		.1000	.001245718	.0001935340	.000	.0006939256	.0017975101
		.1682	.000989852	.0001907988	.000	.0004458580	.0015338451
		.4757	-.000484389	.0001907146	.113	-.001028143	.0000593641
		.8000	-.000398751	.0001782897	.221	-.000907080	.0001095773
	.4757	.0000	.002130375	.0001962024	.000	.0015709749	.0026897749
		.1000	.001730107	.0002000441	.000	.0011597541	.0023004604
		.1682	.001474241	.0001973990	.000	.0009114292	.0020370527
		.2828	.0004843894	.0001907146	.113	-.000059364	.0010281429
		.8000	.0000856382	.0001853359	.997	-.000442780	.0006140565
	.8000	.0000	.002044737	.0001841481	.000	.0015197050	.0025697685
		.1000	.001644469	.0001882360	.000	.0011077822	.0021811559
		.1682	.001388603	.0001854226	.000	.0008599374	.0019172681
		.2828	.0003987512	.0001782897	.221	-.000109577	.0009070797
		.4757	-.000085638	.0001853359	.997	-.000614056	.0004427802

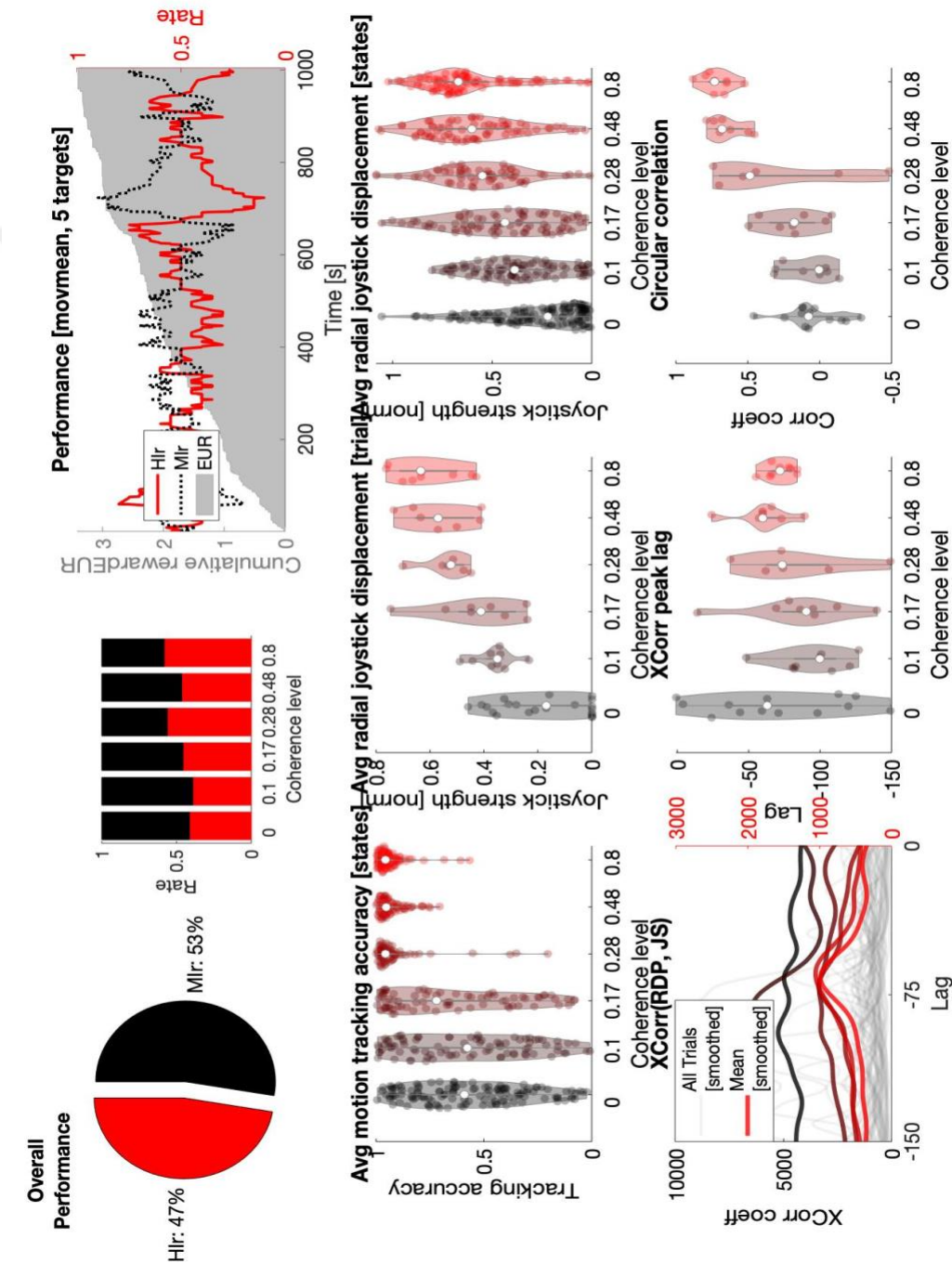
Fixation_Break	.0000	.1000	-.02	.027	.971	-.10	.06
		.1682	.04	.026	.670	-.04	.11
		.2828	.05	.025	.356	-.02	.12
		.4757	.03	.026	.867	-.05	.10
		.8000	.07*	.025	.036	.00	.14
	.1000	.0000	.02	.027	.971	-.06	.10
		.1682	.06	.027	.220	-.02	.14
		.2828	.07	.026	.068	.00	.15
		.4757	.05	.027	.408	-.03	.13
		.8000	.09*	.025	.003	.02	.17
	.1682	.0000	-.04	.026	.670	-.11	.04
		.1000	-.06	.027	.220	-.14	.02
		.2828	.01	.026	.998	-.06	.08
		.4757	-.01	.026	.999	-.08	.07
		.8000	.03	.025	.746	-.04	.10
	.2828	.0000	-.05	.025	.356	-.12	.02
		.1000	-.07	.026	.068	-.15	.00
		.1682	-.01	.026	.998	-.08	.06
		.4757	-.02	.026	.968	-.09	.05
		.8000	.02	.024	.930	-.05	.09
	.4757	.0000	-.03	.026	.867	-.10	.05
		.1000	-.05	.027	.408	-.13	.03
		.1682	.01	.026	.999	-.07	.08
		.2828	.02	.026	.968	-.05	.09
		.8000	.04	.025	.501	-.03	.11
	.8000	.0000	-.07*	.025	.036	-.14	.00
		.1000	-.09*	.025	.003	-.17	-.02
		.1682	-.03	.025	.746	-.10	.04
		.2828	-.02	.024	.930	-.09	.05
		.4757	-.04	.025	.501	-.11	.03
reward	.0000	.1000	-.191851174*	.0539721662	.005	-.345733261	-.037969086
		.1682	-.102852038	.0532505565	.383	-.254676717	.0489726413
		.2828	-.100547838	.0514264516	.369	-.247171742	.0460760668
		.4757	.0823076617	.0532283519	.634	-.069453709	.2340690322
		.8000	-.101953356	.0499581273	.319	-.244390865	.0404841531
	.1000	.0000	.191851174*	.0539721662	.005	.0379690859	.3457332611
		.1682	.0889991359	.0542923570	.572	-.065795860	.2437941316
		.2828	.0913033360	.0525044587	.506	-.058394115	.2410007871
		.4757	.274158835*	.0542705786	.000	.1194259326	.4288917379
		.8000	.0898978173	.0510671396	.492	-.055701639	.2354972734
	.1682	.0000	.1028520376	.0532505565	.383	-.048972641	.2546767165
		.1000	-.088999136	.0542923570	.572	-.243794132	.0657958598
		.2828	.0023042001	.0517623920	1.000	-.145277517	.1498859168
		.4757	.185159699*	.0535529901	.007	.0324727405	.3378466581
		.8000	.0008986814	.0503038745	1.000	-.142524601	.1443219635
	.2828	.0000	.1005478375	.0514264516	.369	-.046076067	.2471717419
		.1000	-.091303336	.0525044587	.506	-.241000787	.0583941152
		.1682	-.002304200	.0517623920	1.000	-.149885917	.1452775167
		.4757	.182855499*	.0517395488	.006	.0353389118	.3303720867
		.8000	-.001405519	.0483687703	1.000	-.139311552	.1365005147
	.4757	.0000	-.082307662	.0532283519	.634	-.234069032	.0694537088
		.1000	-.274158835*	.0542705786	.000	-.428891738	-.119425933
		.1682	-.185159699*	.0535529901	.007	-.337846658	-.032472741
		.2828	-.182855499*	.0517395488	.006	-.330372087	-.035338912
		.8000	-.184261018*	.0502803686	.003	-.327617281	-.040904754
	.8000	.0000	.1019533562	.0499581273	.319	-.040484153	.2443908654
		.1000	-.089897817	.0510671396	.492	-.235497273	.0557016388
		.1682	-.000898681	.0503038745	1.000	-.144321964	.1425246007
		.2828	.0014055186	.0483687703	1.000	-.136500515	.1393115520
		.4757	.184261018*	.0502803686	.003	.0409047543	.3276172815

Based on observed means.
The error term is Mean Square(Error) = .870.

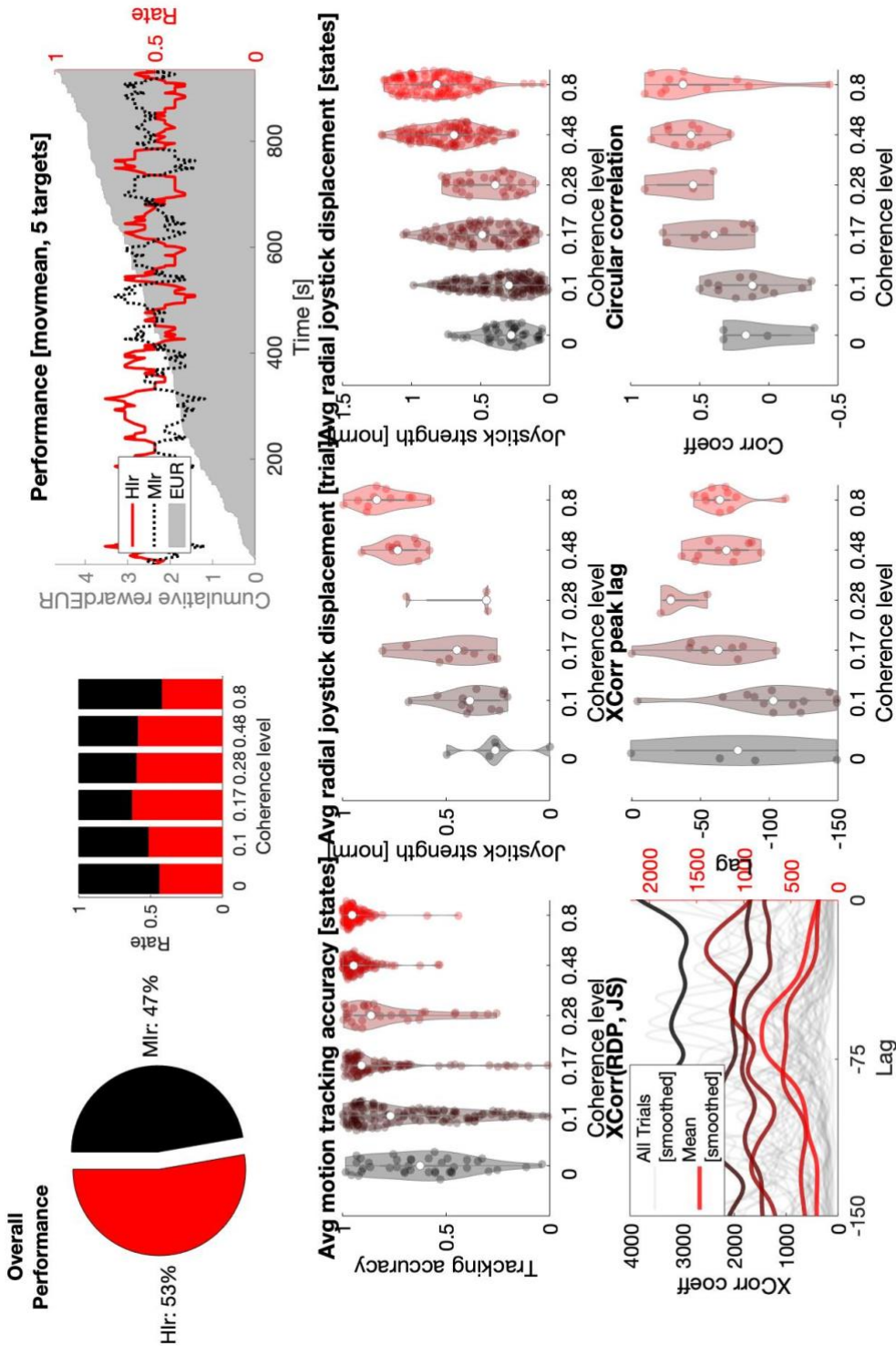
*. The mean difference is significant at the .05 level.

APPENDIX F

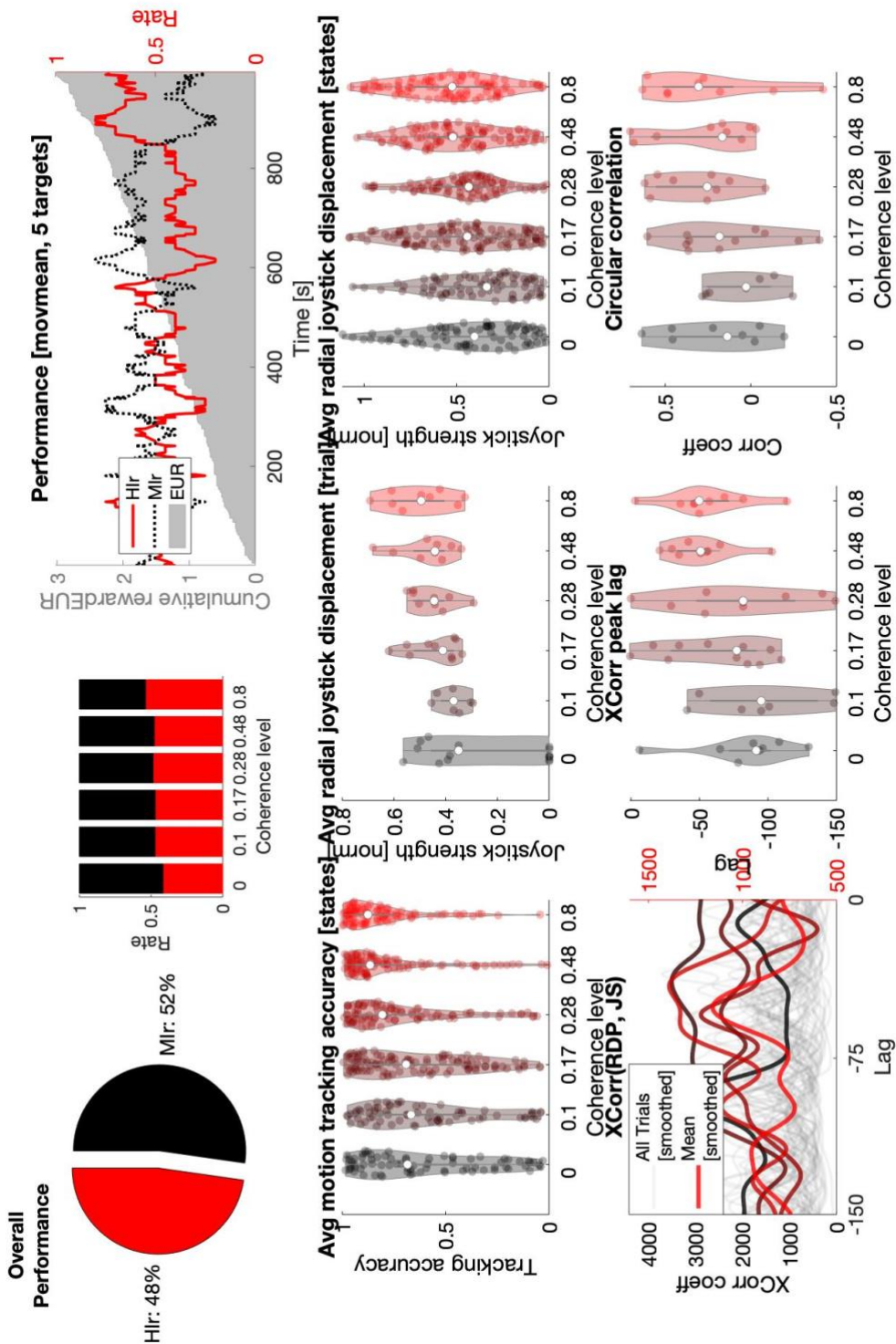
Subject 1



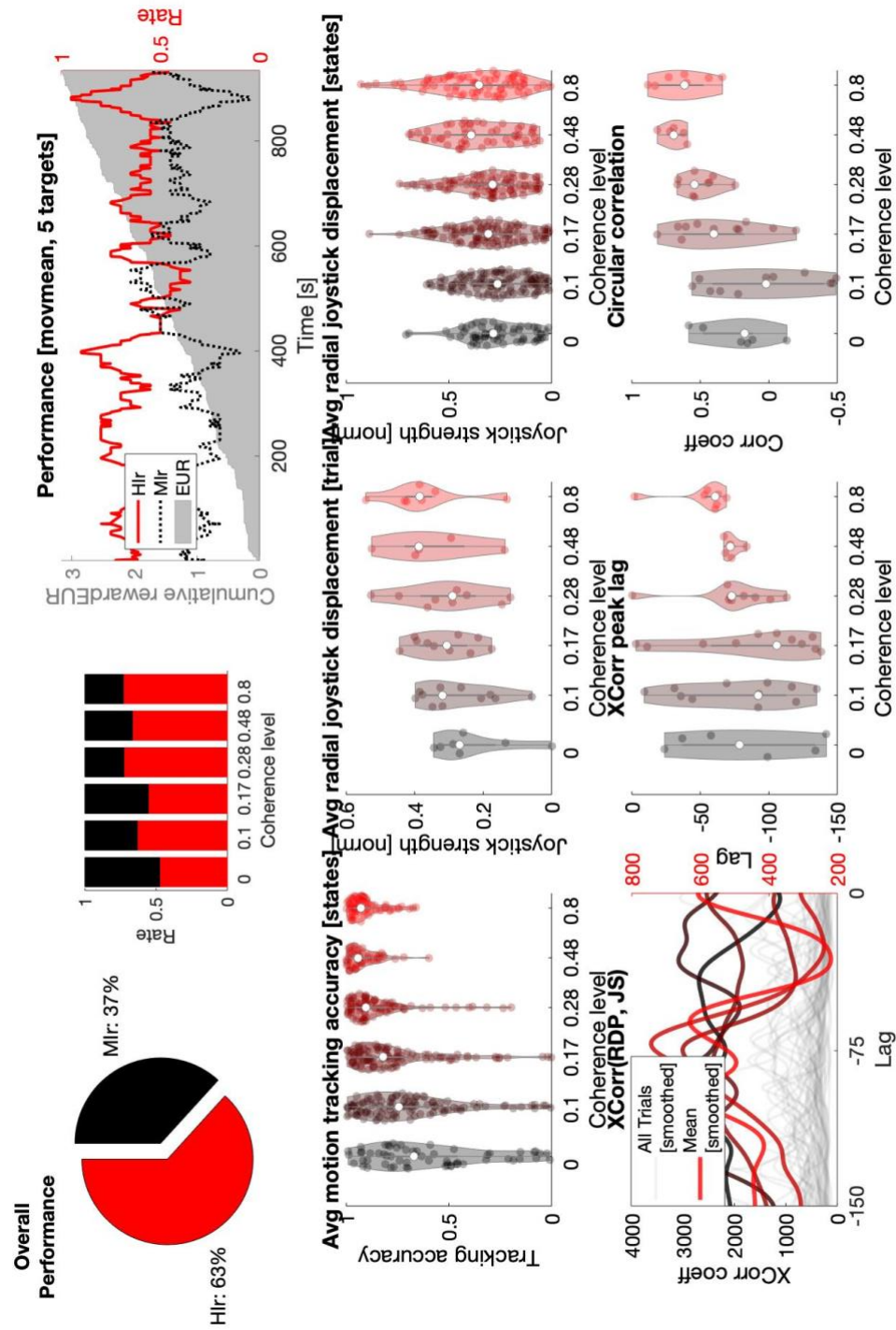
Subject 2



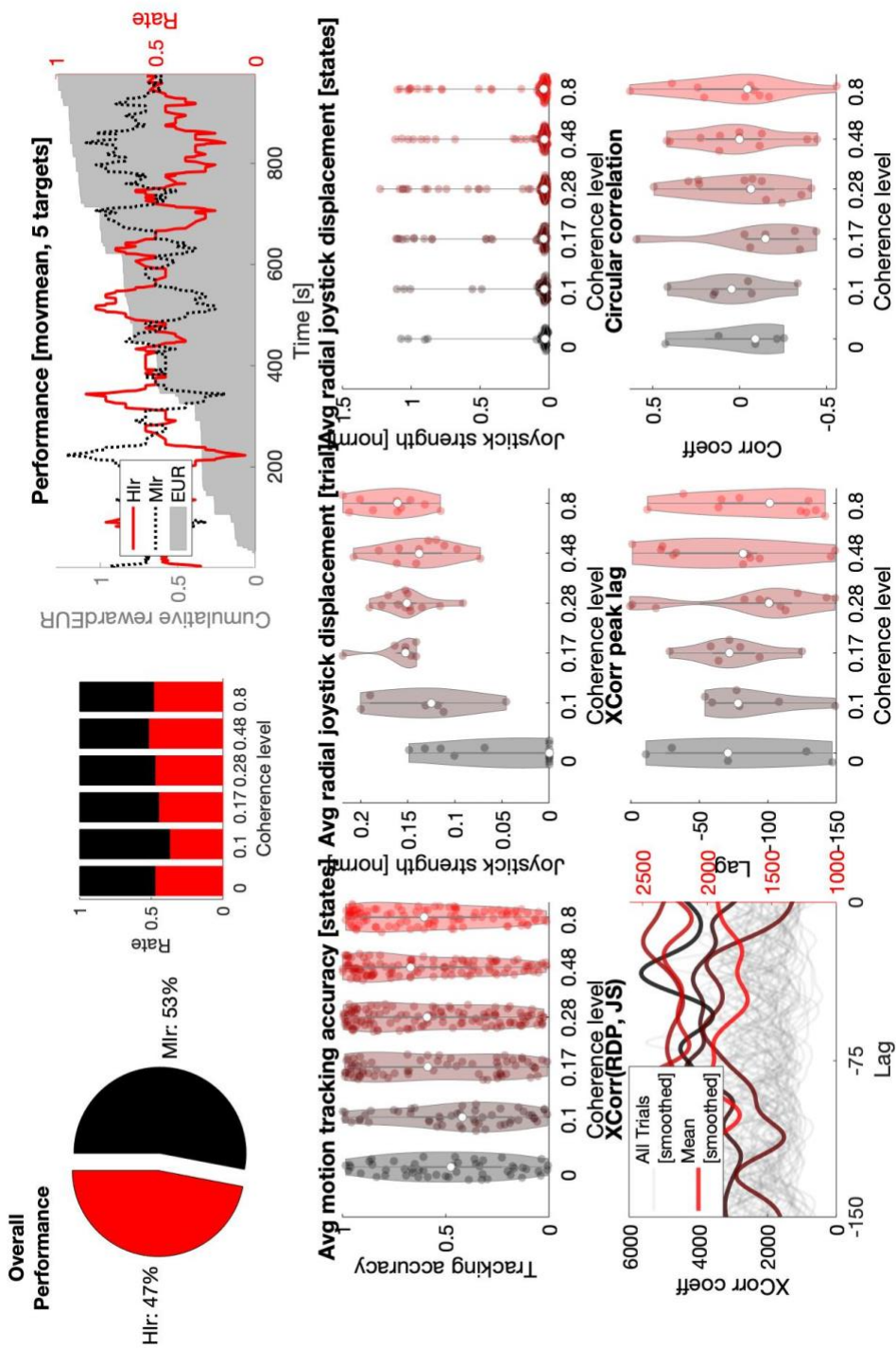
Subject 3



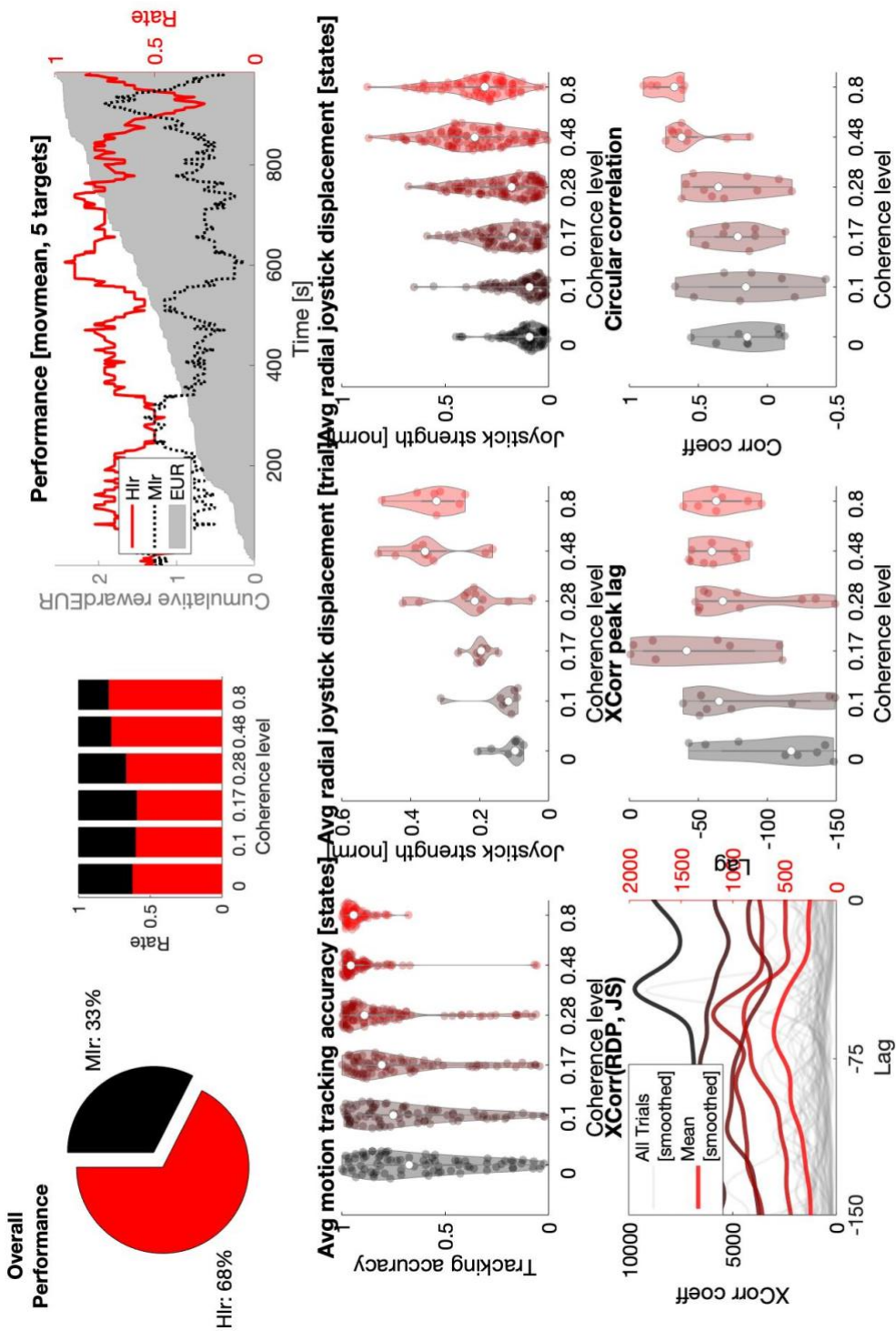
Subject 4

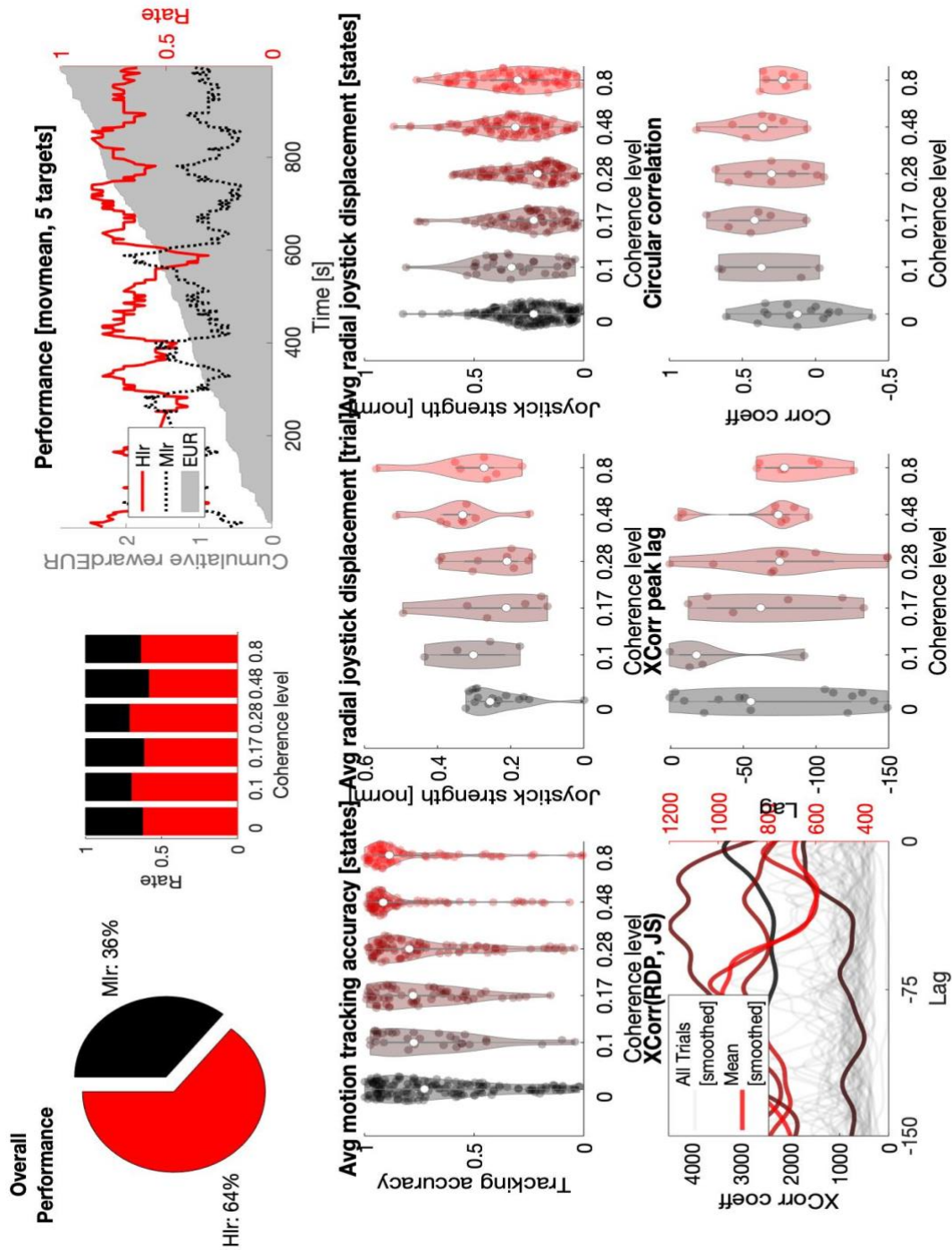


Subject 5

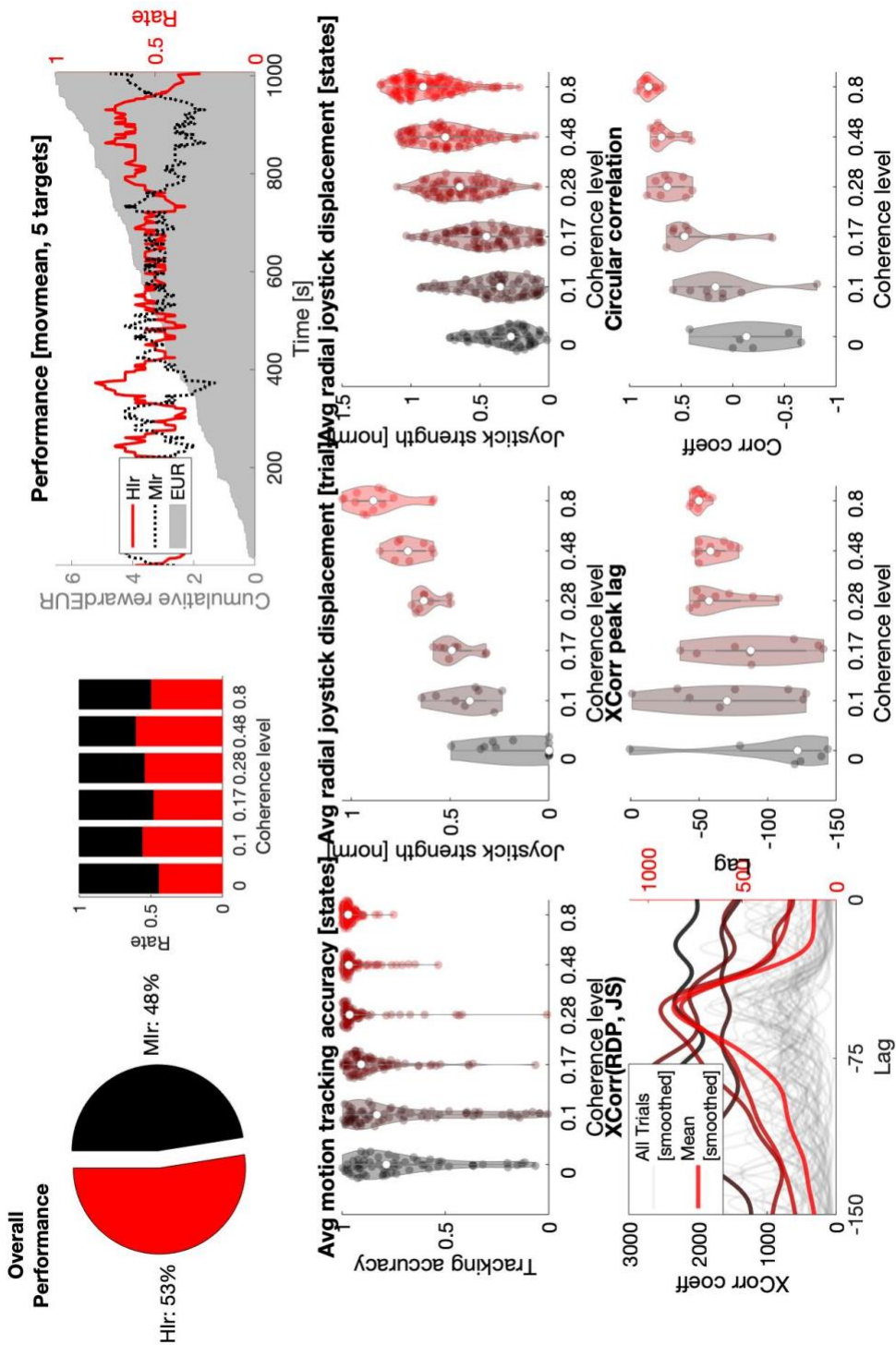


Subject 6

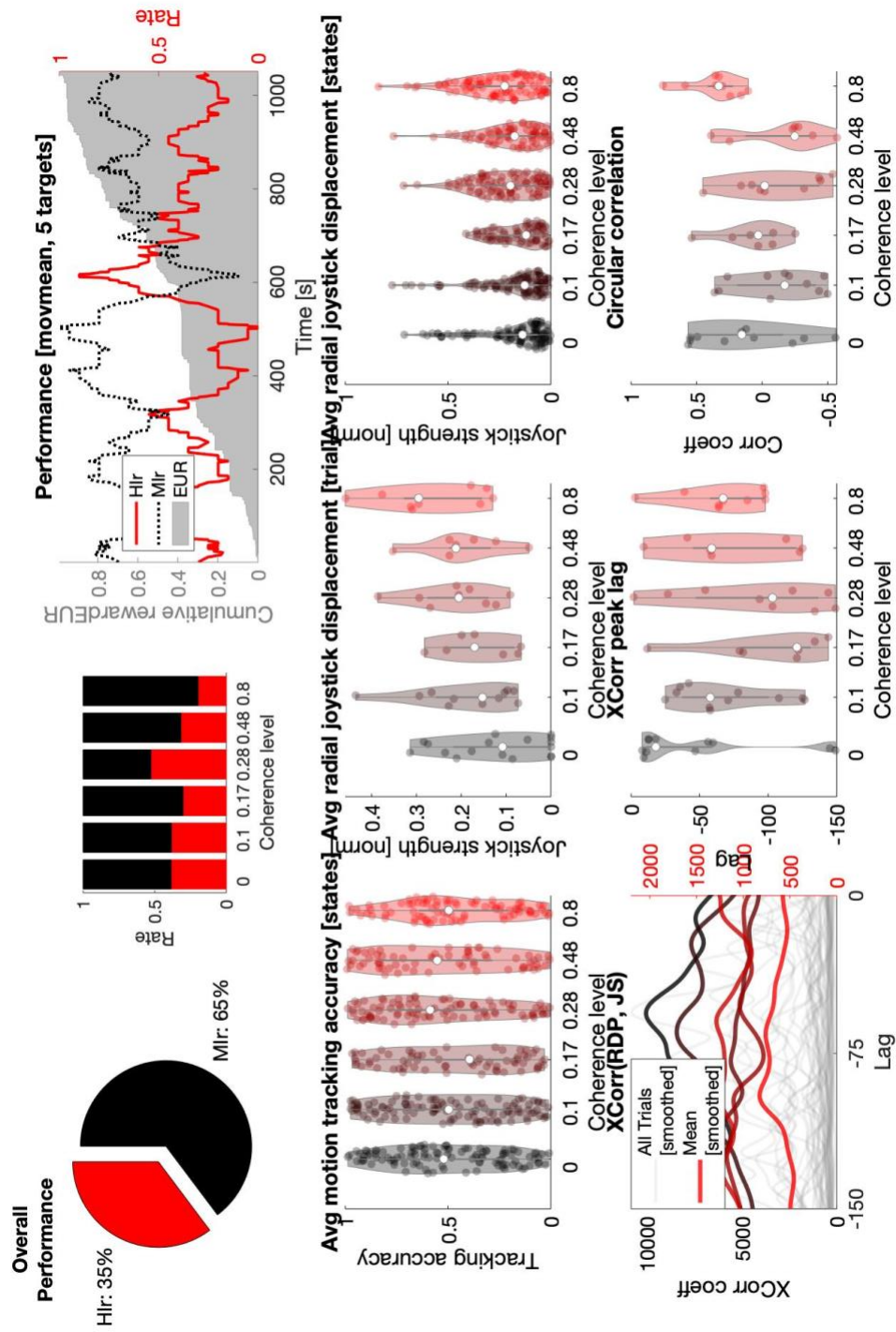




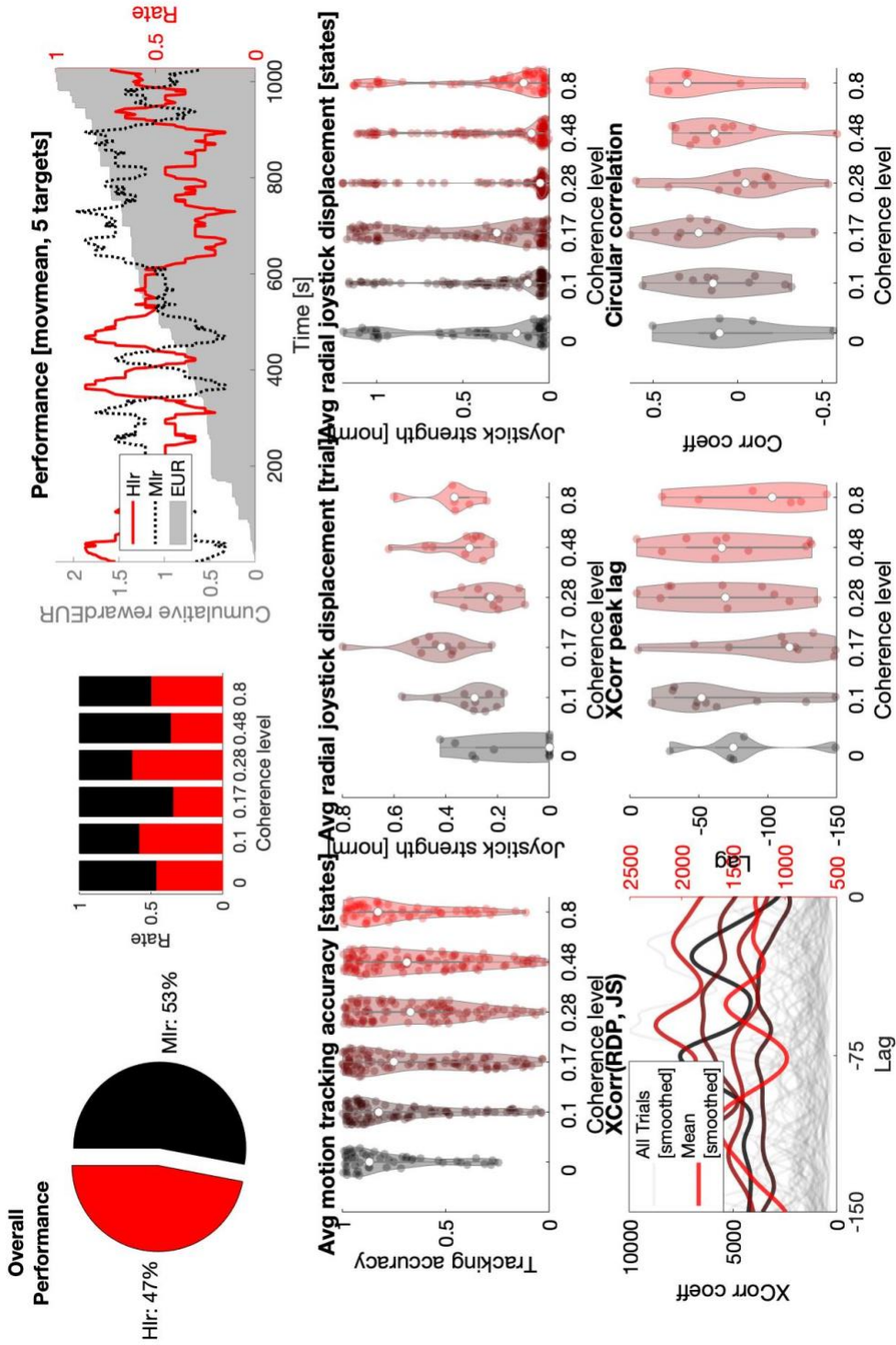
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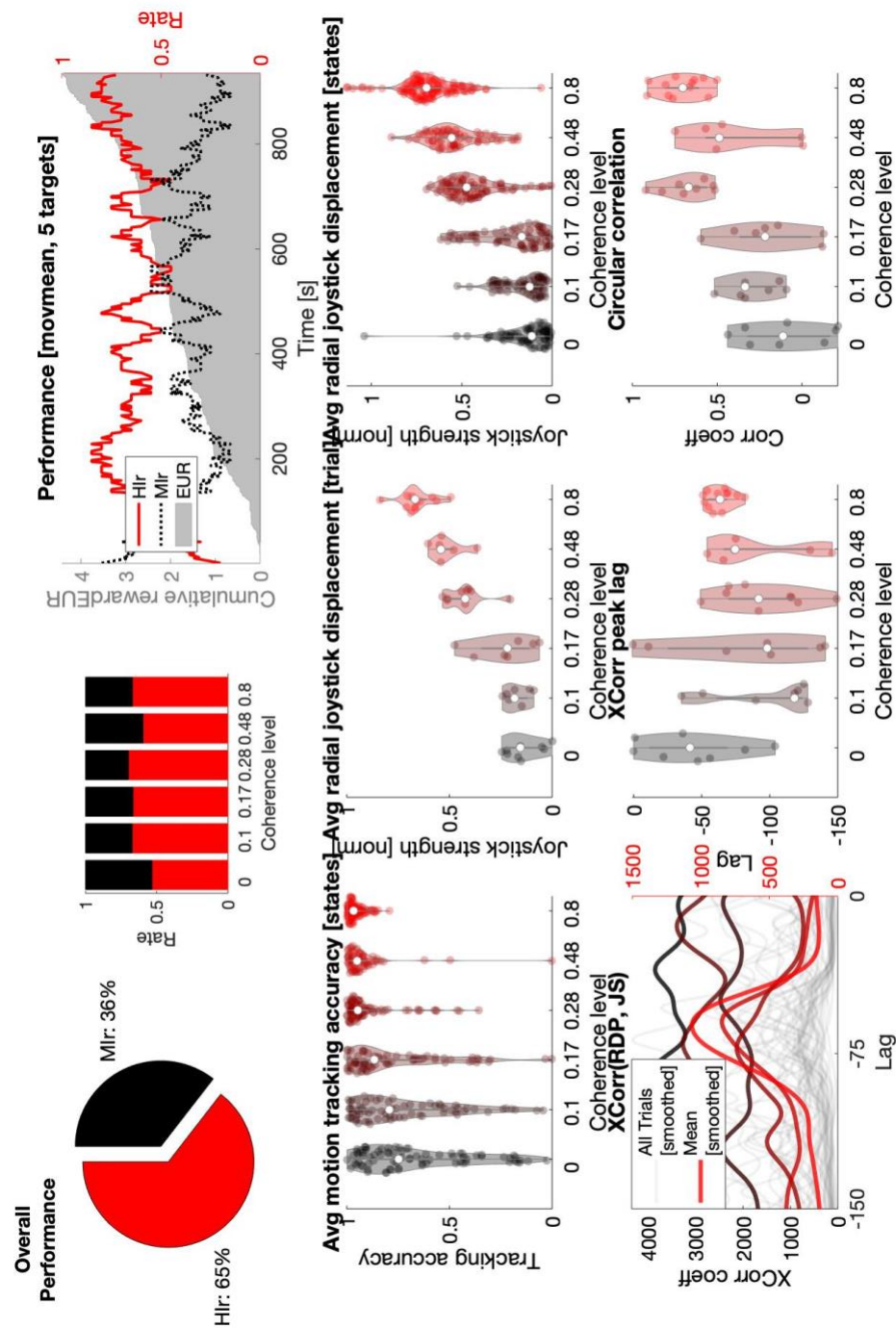
Subject 9



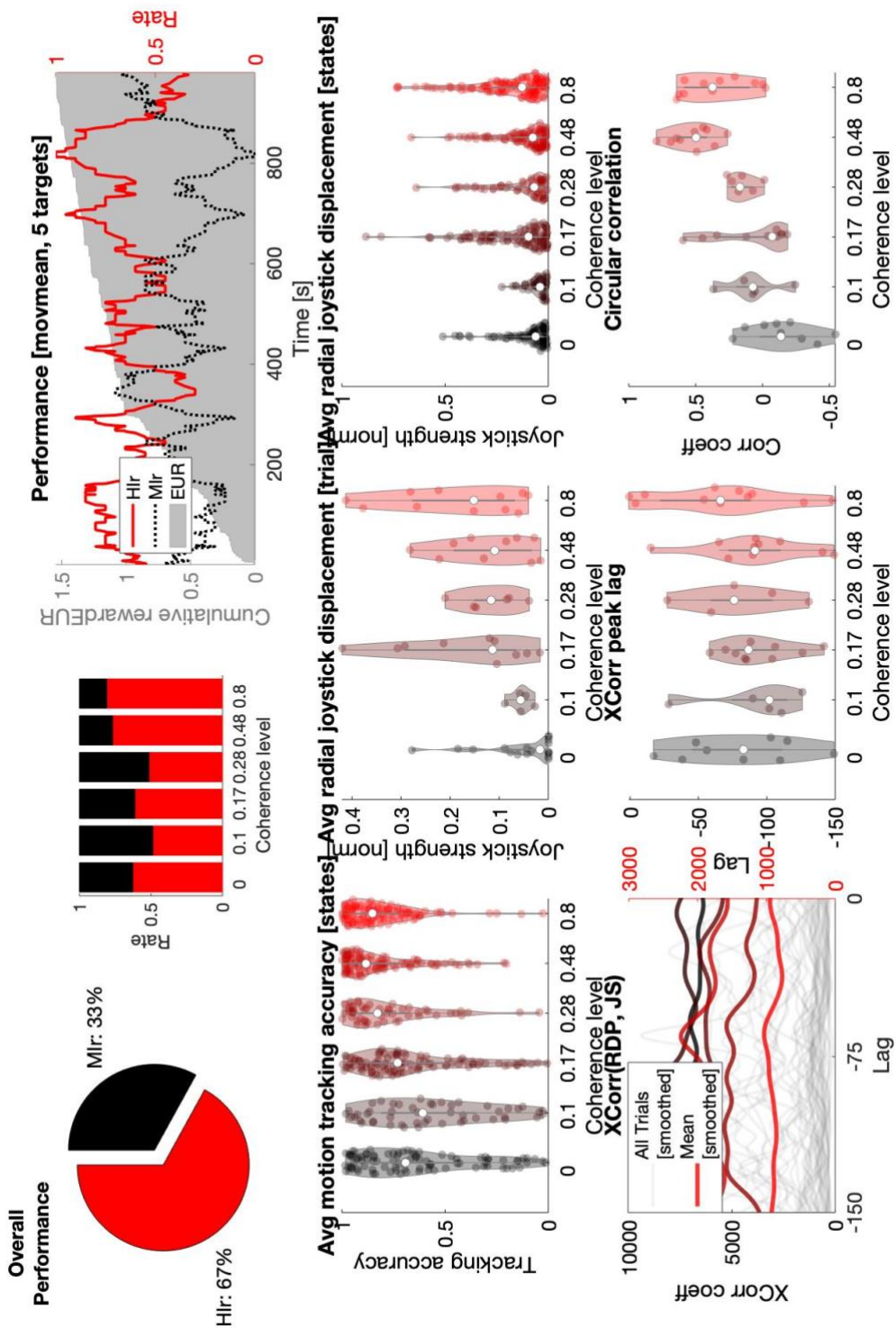
Subject 10



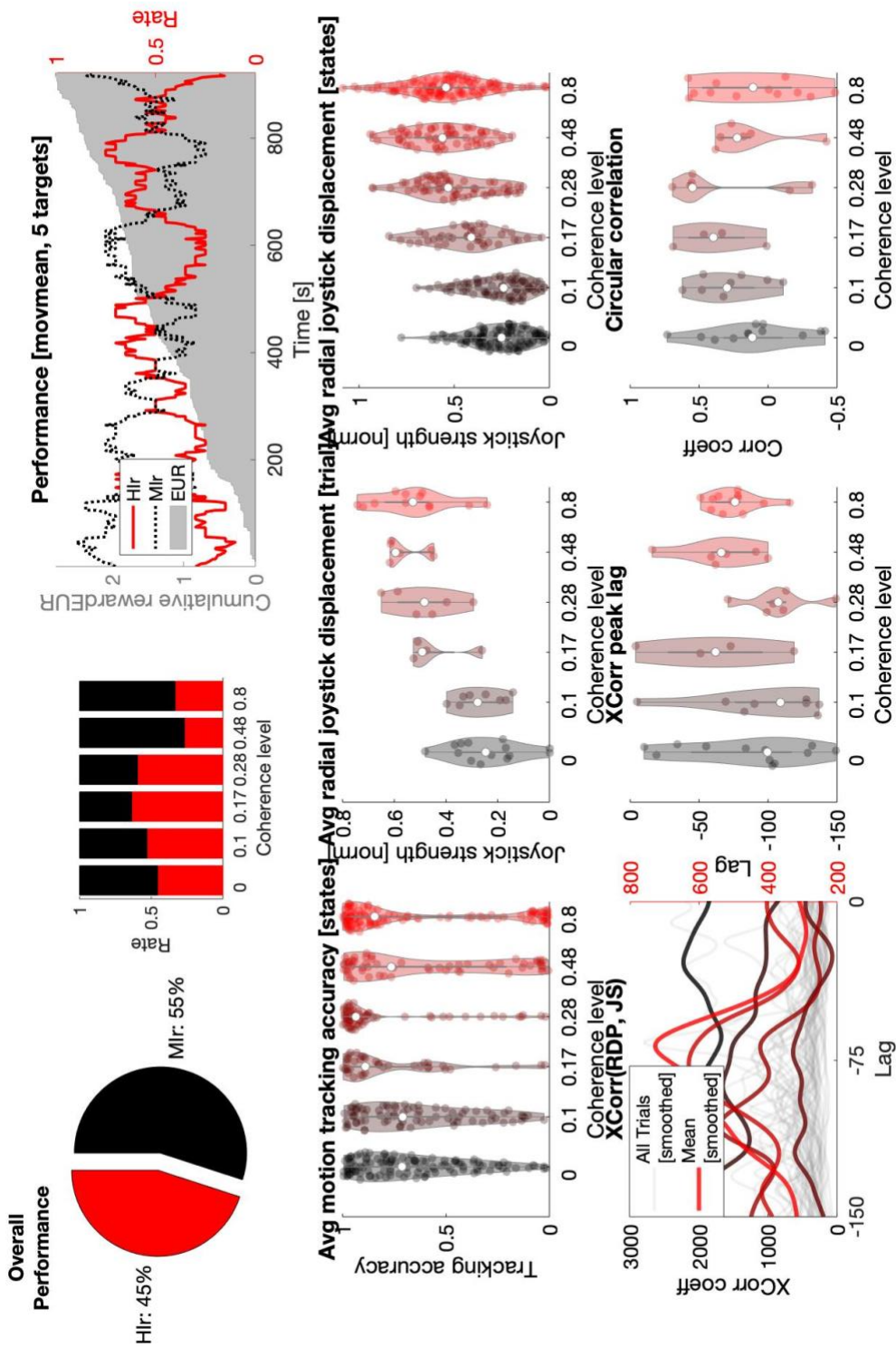
Subject 11



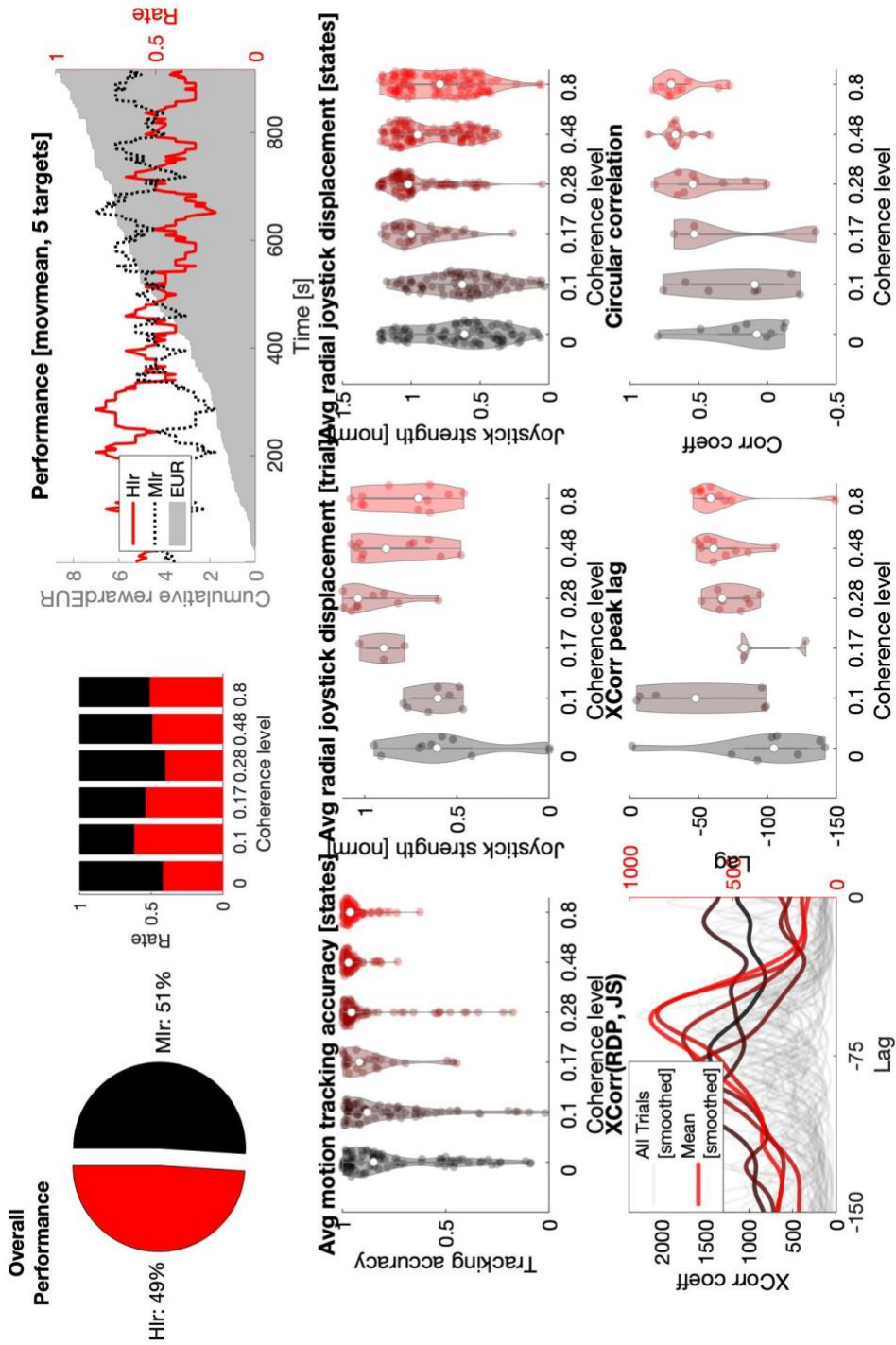
Subject 12



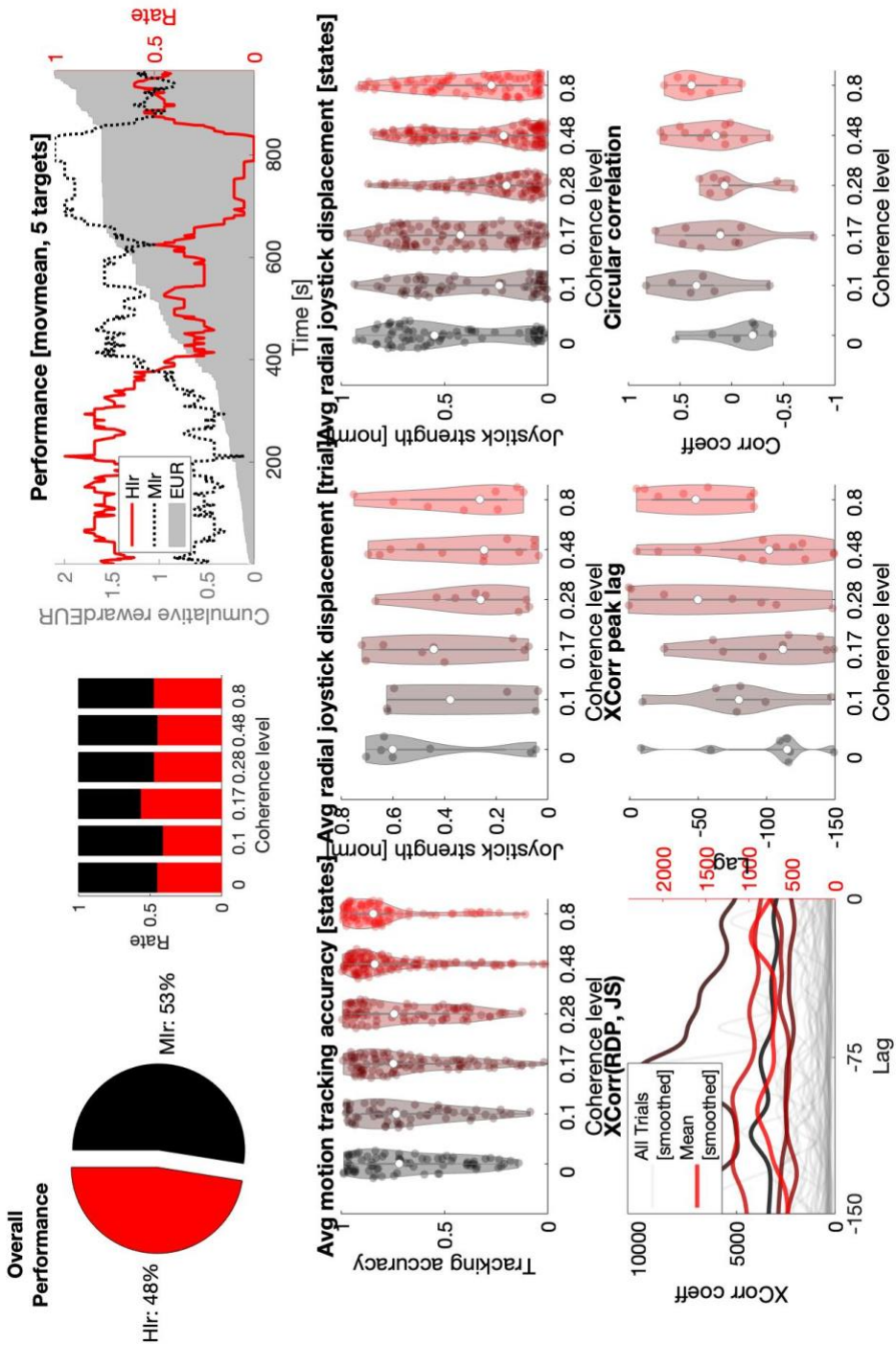
Subject 13



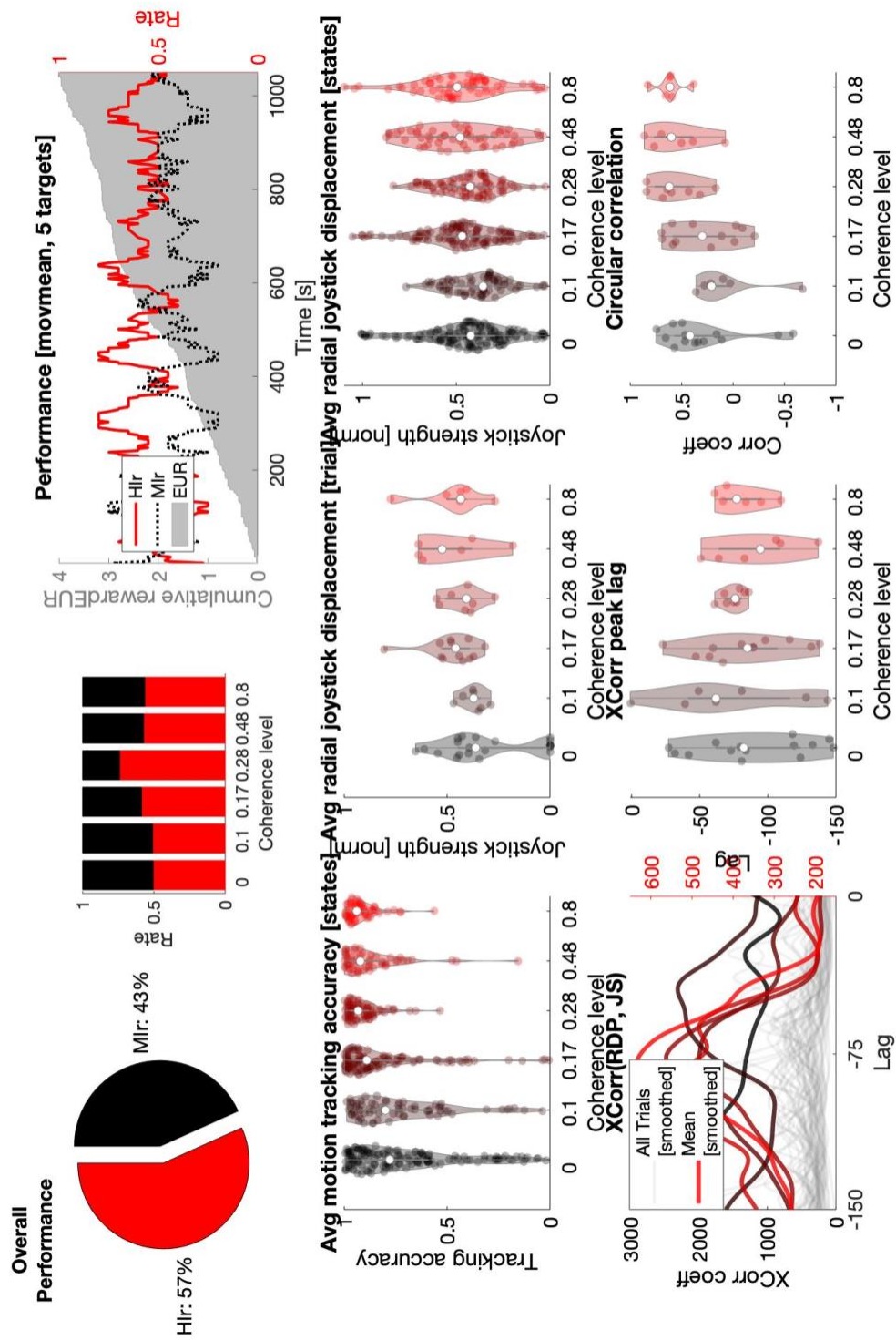
Subject 14



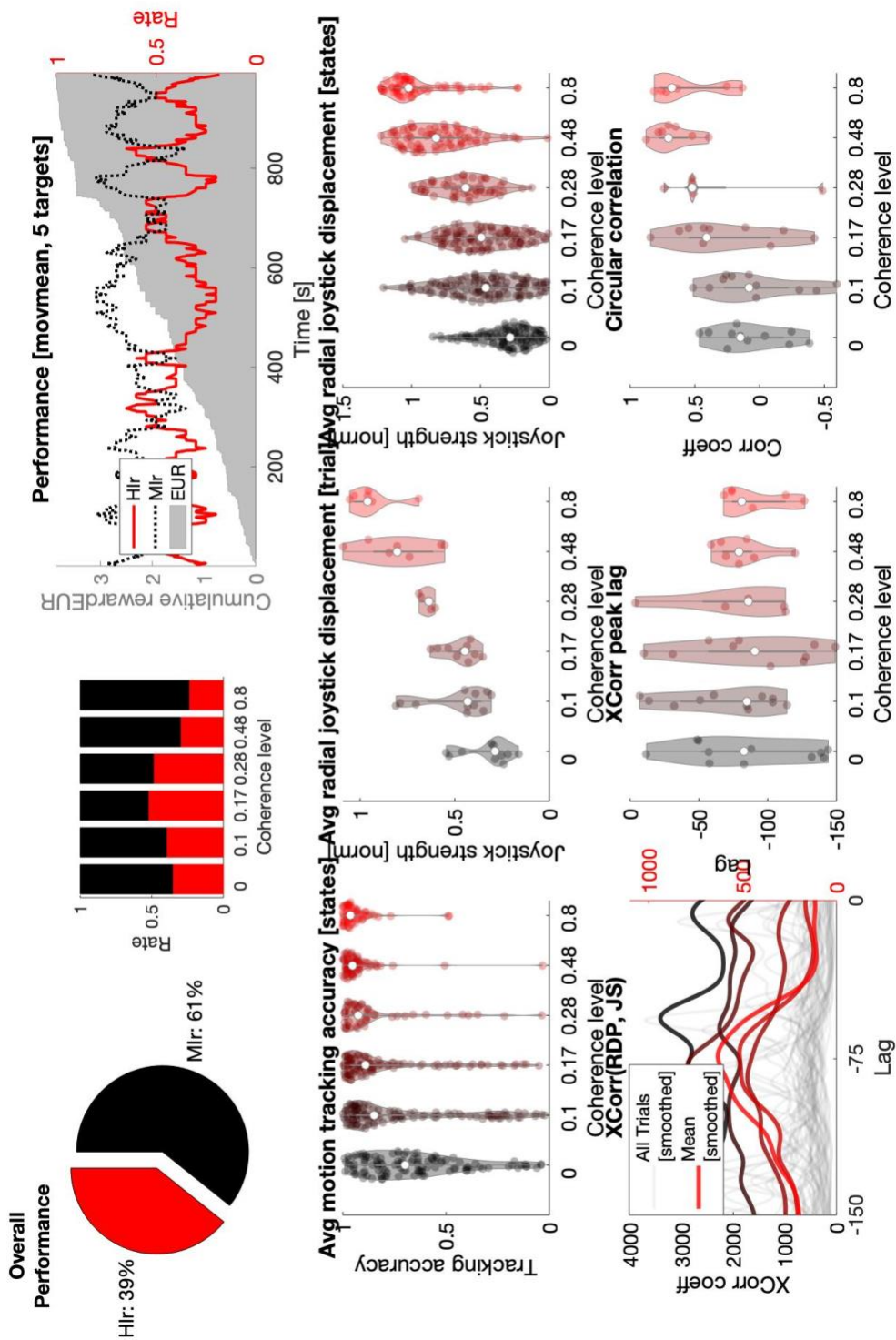
Subject 15



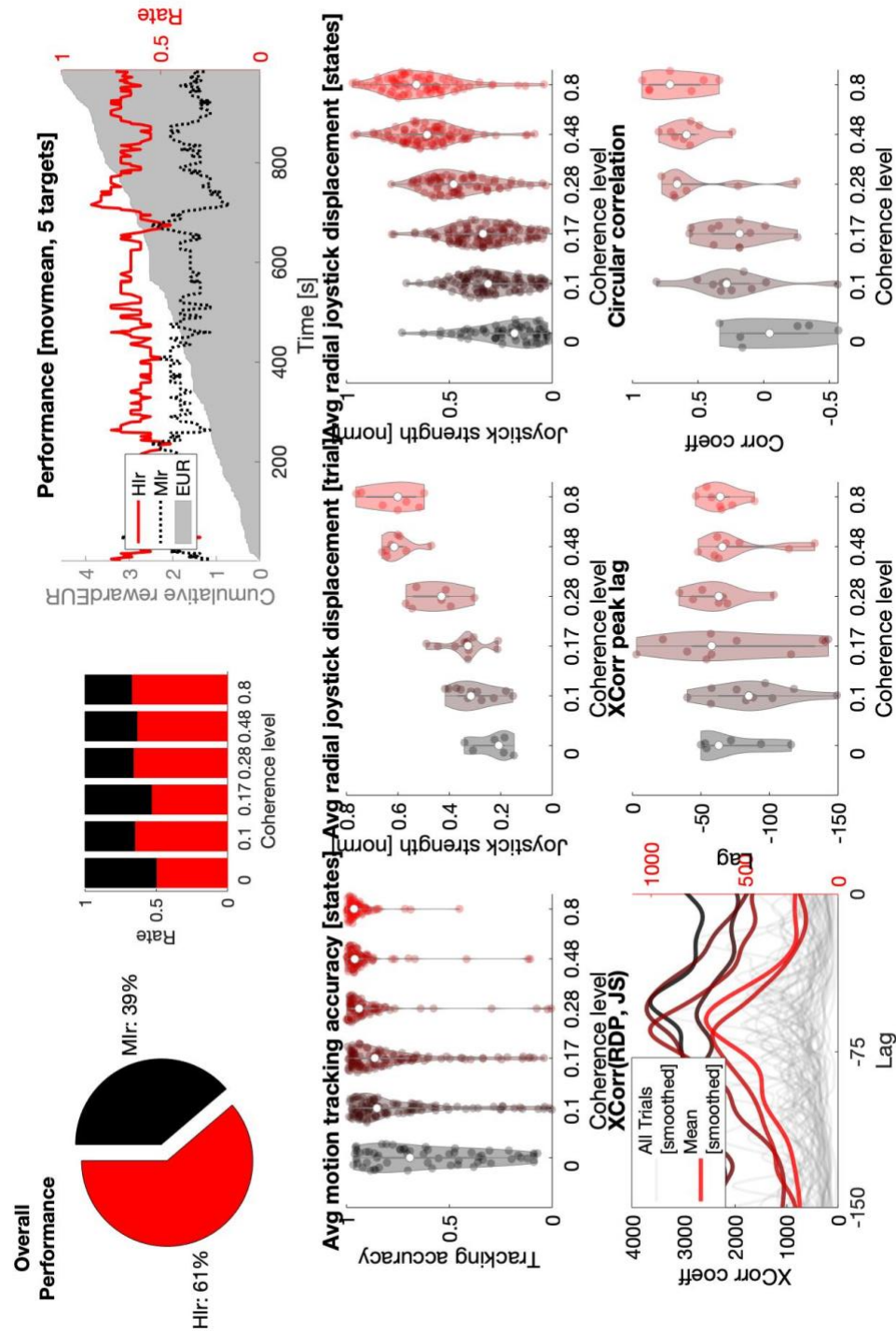
Subject 16



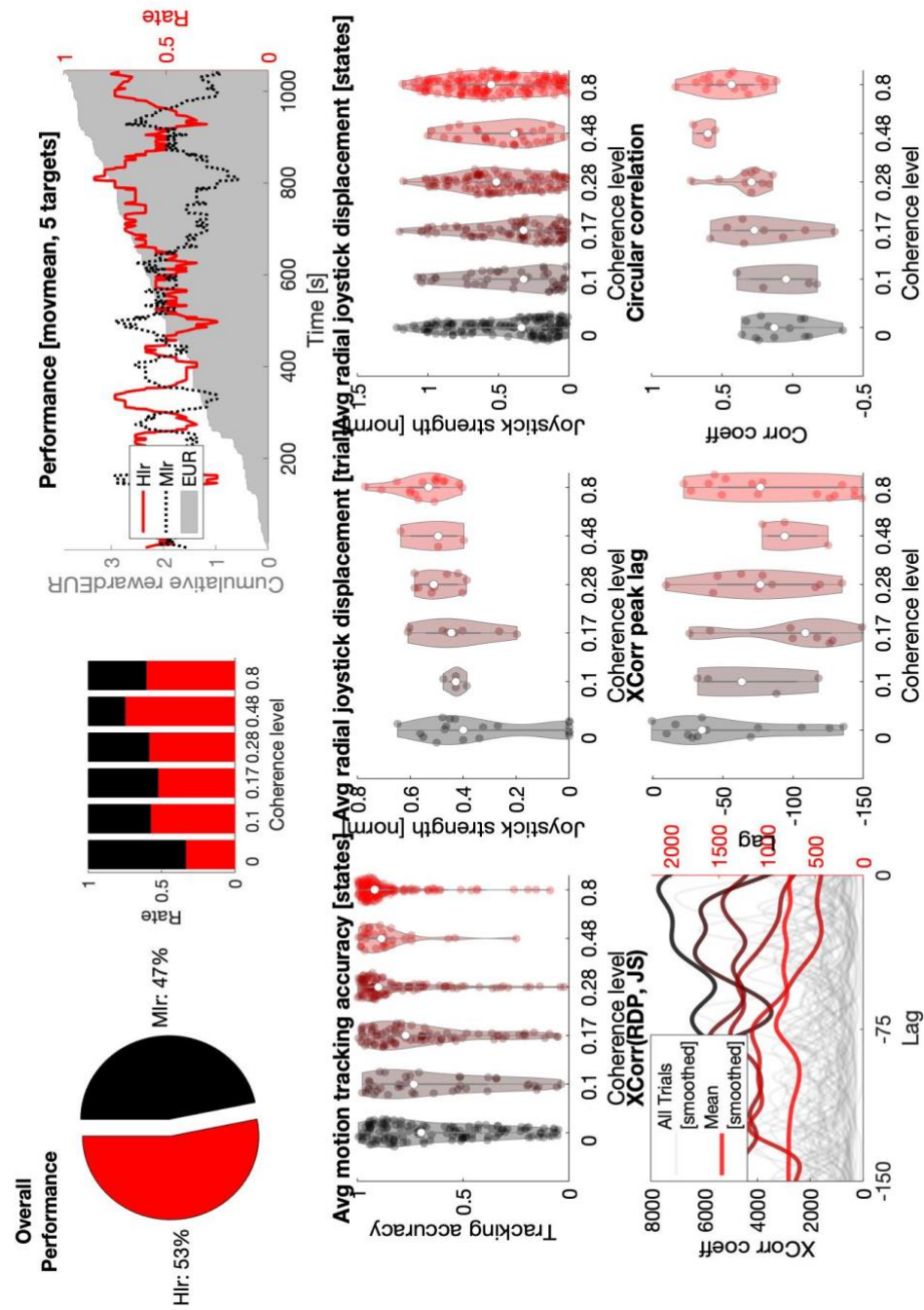
Subject 17

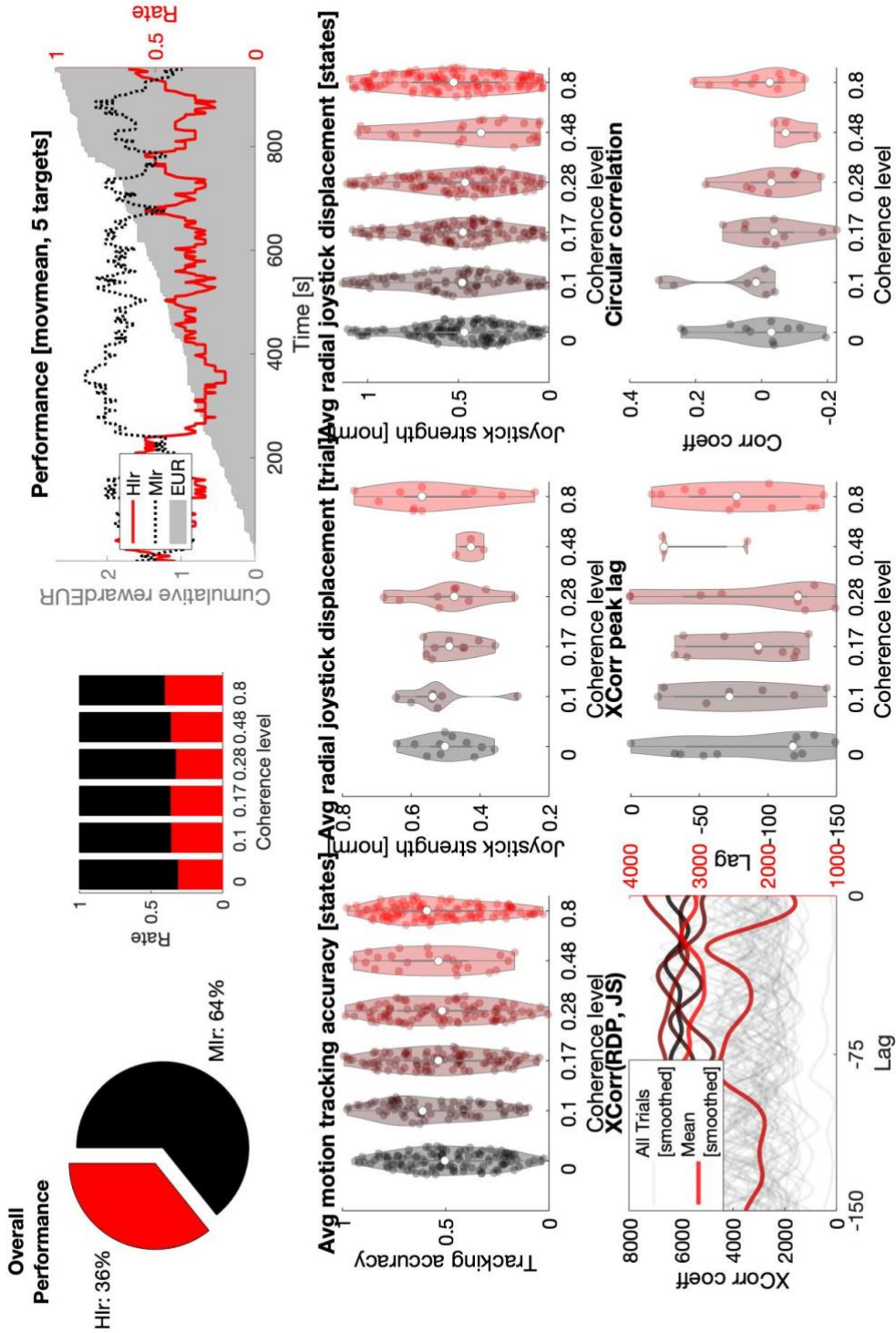


Subject 18

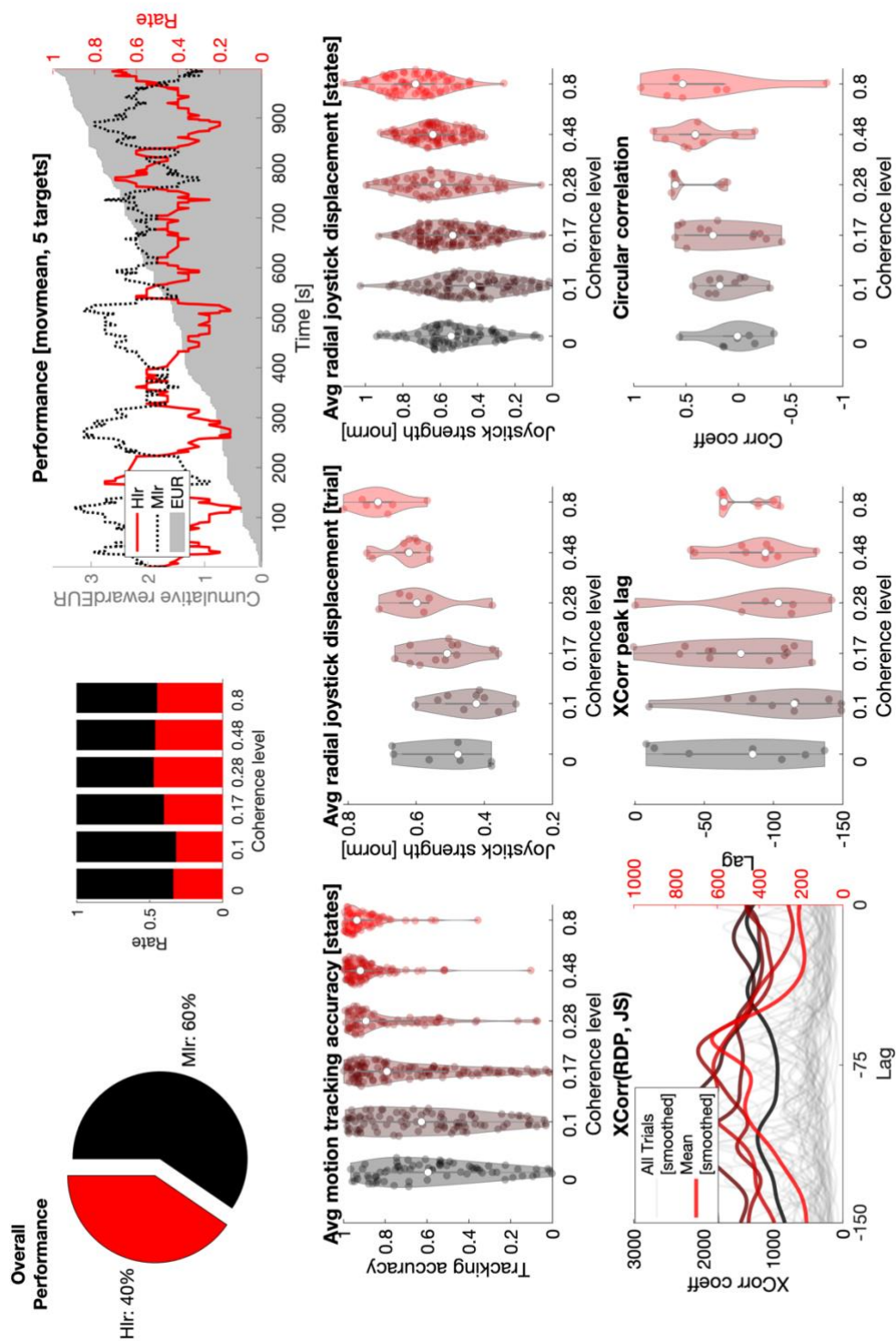


Subject 19





Subject 21



Subject 22

