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Mapping the structure of perceptual and visual–motor abilities in healthy young adults

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ABSTRACT

The ability to quickly detect and respond to visual stimuli in the environment is critical to many human activities. While such perceptual and visual–motor skills are important in a myriad of contexts, considerable variability exists between individuals in these abilities. To better understand the sources of this variability, we assessed perceptual and visual–motor skills in a large sample of 230 healthy individuals via the Nike SPARQ Sensory Station, and compared variability in their behavioral performance to demographic, state, sleep and consumption characteristics. Dimension reduction and regression analyses indicated three underlying factors: Visual–Motor Control, Visual Sensitivity, and Eye Quickness, which accounted for roughly half of the overall population variance in performance on this battery. Inter-individual variability in Visual–Motor Control was correlated with gender and circadian patters such that performance on this factor was better for males and for those who had been awake for a longer period of time before assessment. The current findings indicate that abilities involving coordinated hand movements in response to stimuli are subject to greater individual variability, while visual sensitivity and occulomotor control are largely stable across individuals.

1. Introduction

Success in many human endeavors requires individuals to efficiently process visual information to generate swift and appropriate motor actions. Whether driving a car, playing sports, or walking around town, people must be able to see what is around them, direct their attention to the most relevant information, and orient their bodies to successfully react to the changing environment. Despite the importance of these perceptual and visual–motor abilities, there is considerable variability between individuals in their capacity to see and react. In fact, inter-individual variability in sensory-guided motor behavior abilities has been utilized across a great number of studies aimed at understanding what factors contribute to greater or lesser achievement in different applied settings. The results of these studies indicate that better perceptual and visual–motor skills are predictive of success in a number of important endeavors, including industrial job performance (Hunter, 1986; Hunter & Hunter, 1984), military duties (Griffin & Koonce, 1996; Johnston & Catano, 2002; King et al., 2013), and surgical performance (Datta et al., 2002; Maan, Maan, Darzi, & Aggarwal, 2012). In a similar vein, two recent meta reviews of the sports expertise literature demonstrate that certain visual–perceptual abilities are enhanced in more accomplished athletes, relative to less accomplished athletes (Mann, Williams, Ward, & Janelle, 2007; Voss, Kramer, Basak, Prakash, & Roberts, 2010). Taken together, these studies indicate the need for proficient visual and motor skills and the presence of considerable variability in these skills across the population. Thus, the aim of the current study is to better understand the sources of this inter-individual variability across a small set of demographic and state characteristics in a sample of healthy young adults.

1.1. Measuring perceptual and visual–motor skills

Given the importance of perceptual and visual–motor skills and the literature showing that they are predictive of success in applied pursuits, there is a growing movement towards developing tools to assess and train these abilities. Among these tools is the Nike SPARQ Sensory Station (Nike, Inc., Beaverton, Oregon), a computerized assessment device equipped with a battery of nine psychometric tasks that are administered with video instructions in about 30 min by certified trainers. The interactive tasks are measures of Static Visual Acuity, Contrast Sensitivity, Depth Perception, Near-Far Quickness, Dynamic Visual Acuity, Perception Span, Eye–Hand Coordination, Go/No-Go and Hand Response Time that have previously been identified as important abilities for sports (Erickson, 2012; Hitzeman & Beckerman, 1993). This

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battery includes information about the participant (e.g. age, gender, height, sport, level, position, concussion history), followed by a series of behavioral tasks that are arranged hierarchically so that stimuli presented later in the battery are scaled according to sensitivity thresholds measured in early tasks.

The Sensory Station devices have been deployed in a number of athletic, clinical, and military training facilities (http://www.ssusersgroup.weebly.com), and offer a broad platform from which to study perceptual and visual–motor skills in applied contexts. Test–retest reliability on the Sensory Station has been replicated in two samples (Erickson et al., 2011; Gilrein, 2014), both of which demonstrated stable test–retest performance on assessments of Static Visual Acuity, Contrast Sensitivity, Depth Perception, Dynamic Visual Acuity, and Hand Response Time, while moderate re-test improvements were found for the Near–Far Quickness, Perception Span, Eye–Hand Coordination, and Go/No-Go measures. Moreover, when measured over 10 successive sessions, learning in these tasks was principally linear with as much as 60% improvement in some tasks (Krasich et al., under review). Recent studies have also begun to establish a direct external validity between the Sensory Station battery and real-world performance. For example, using logistic regression techniques, it was shown that better performance on the Perception Span, Near–Far Quickness, Go/No-Go and Hand Reaction Time tasks accounted for 69% of the variability in goals scored over two seasons in a sample of 42 collegiate hockey players (Poltavski & Biberdorff, 2014). Additionally, in comparing overall performance on the Sensory Station battery among 38 men's varsity football players, worse overall scores were associated with an increased likelihood of sustaining severe head impacts during practices and games, indicating a link between collision avoidance and perceptual and visual–motor skills (Harpham, Mihalik, Littleton, Frank, & Guskiewicz, 2014). Together, these studies suggest that the perceptual and visual–motor abilities measured by the Sensory Station are related to important performance outcomes, and further indicate the need to understand how variability in these skills is expressed across individuals.

1.2. Factors influencing perceptual and visual–motor performance

Performance on perceptual and visual–motor tasks can be greatly affected by a number of individual-difference characteristics. Gender differences, specifically, have been demonstrated in many studies, with males demonstrating faster motor speeds (Kauranen & Vanharanta, 1996; Ruff & Parker, 1993; Thomas & French, 1985), better eye–hand coordination, and better visual–spatial abilities (Ruff & Parker, 1993; Thomas & French, 1985; Voyer, Voyer, & Bryden, 1995), whereas females exhibit faster perceptual processing speeds and greater verbal fluency (e.g., Halpern, Straight, & Stephenson, 2011; Kimura 1999; Voyer et al., 1995). These well-documented gender differences in various psychomotor and cognitive abilities provide an initial expectation that gender differences may be observed in the perceptual and visual–motor tasks.

In addition to gender differences, research has also shown that perceptual and visual–motor performance can be substantially modulated by an individual's psychological state. For example, current stress and anxiety levels are often negatively correlated with cognitive and motor performance (e.g., Bolmont, Gangloff, Vouriot, & Perrin, 2002; Han et al., 2011; Raglin, 1992). Past research has also highlighted the role of affect state in modulating task performance, with higher positive state affect and lower negative state affect being associated with better cognitive (Fredrickson & Branigan, 2005; Muraven & Baumeister, 2000), athletic (Skinner & Brewer, 2004), and work performance (Kaplan, Bradley, Luchman, & Haynes, 2009; Wright, Cropanzano, & Meyer, 2004). Specifically, positive emotions have been shown to facilitate effective competition preparation, and benefit subsequent performance (Skinner & Brewer, 2002, 2004). Therefore, participants' stress level and affective state should also been taken into account when assessing individual differences in perceptual and visual–motor performance.

Finally, previous research has shown that circadian rhythm, and specifically the sleep–wake cycle, is another important factor that influences individual performance on sensory, motor, reaction time, time estimation, and memory tasks (Carrier & Monk, 2000, for a review; Matchock & Mordkoff, 2007; Breimhorst, Falkenstein, Marks, & Griefahn, 2008; Jarraya, Jarraya, Chtourou, Souissi, & Chamari, 2013). In healthy adults who typically sleep from 23:00 to 7:00, peak cognitive performance is often observed during 16:00–22:00 while the lowest levels of performance are reported between 7:00 and 10:00 (Matchock, 2010; Valdez, Ramírez, & García, 2012); however, caffeine and food consumption can alter normal biological rhythms (Valdez et al., 2012).

1.3. The current study

In light of the associations described above, the present study sought to investigate inter-individual variability in perceptual and visual–motor abilities by measuring behavioral performance on the Sensory Station battery, and relating variability in this performance to gender, psychological state, sleep, and consumption history for each of the 230 healthy college-aged participants. For this purpose, the individual Sensory Station measures were submitted to dimension reduction analyses to identify latent factors that underlie perceptual and visual–motor abilities, and then regression analyses were performed on each of the identified latent factors to determine the influence of those individual-difference characteristics. By quantifying performance in these important visual and motor skills, and their relationship to a small set of individual-difference characteristics, the present study provides a platform for understanding how variability in perceptual and visual–motor abilities can affect human performance.

2. Method

2.1. Participants

Two hundred and thirty individuals (105 males, 125 females) completed in a series of assessments across multiple testing sessions as part of a larger research endeavor conducted in the Perception Performance and Psychophysiology Lab at the Duke University Medical Center. The participants ranged in age from 18 to 24 years (Mean = 20.5, SD = 1.6), and were not current or former collegiate varsity athletes. They were compensated $20/h and voluntarily participated under an experimental protocol approved by Duke University's Institutional Review Board. All participants completed a general protocol that included at least two types of assessments: psychophysical measurement of visual and visual–motor abilities assessed by the Nike SPARQ Sensory Station, and self-report questionnaires about their psychological state, recent sleep/circadian rhythm, and consumption history.

2.2. Psychophysical measures

2.2.1. Nike SPARQ Sensory Station

Psychophysical measures were performed on the Nike SPARQ Sensory Station (Nike Inc., Beaverton OR). The Sensory Station battery consists of nine computerized tasks; four of the nine tasks measure visual sensitivity thresholds and the other five tasks assess visual and visual–motor abilities. Brief descriptions for each task are included below, and schematic illustrations are displayed in Fig. 1. More detailed reports of task procedures are included in Erickson et al. (2011) and Poltavski and Biberdorff (2014).

2.2.1.1. Staircase visual sensitivity tasks. The four tasks measuring visual sensitivity – Static Visual Acuity, Dynamic Visual Acuity, Contrast Sensitivity and Depth Perception – were presented on a 23-inch display monitor, with participants standing 16 ft (4.9 m) away from the Station and responding via a handheld Apple iPod touch® (Apple Inc., Cupertino,