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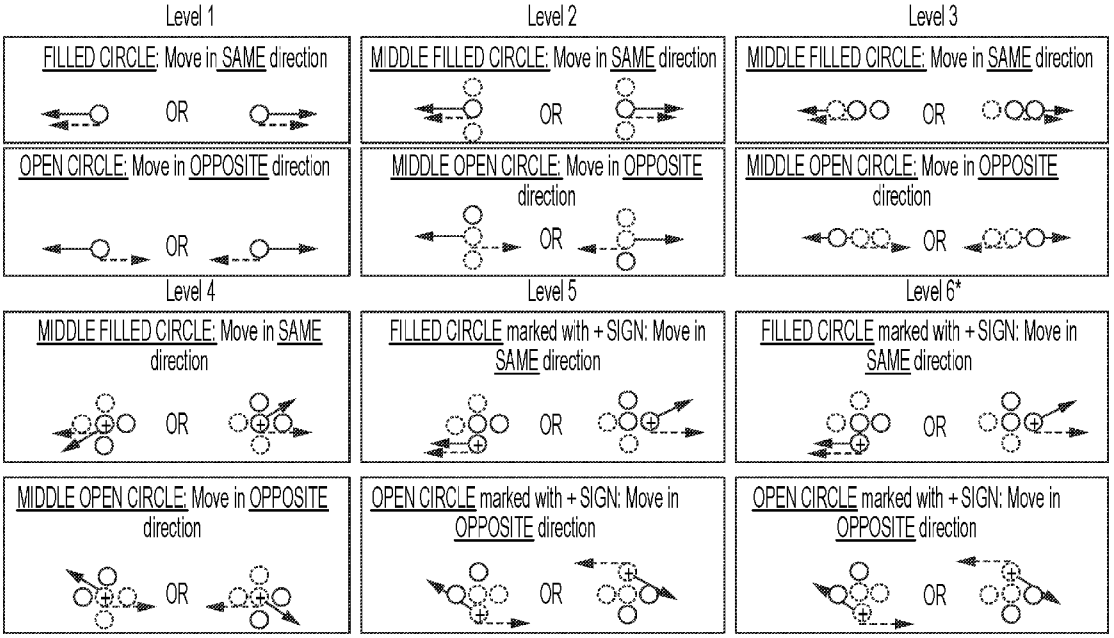

FIG. 1

(57) **Abstract:** The present disclosure generally relates to systems and methods for assessment and training of brain function, specifically processes associated with perceptual-motor efficiency. In certain aspects, a discrimination task, or other perceptual-motor tasks involving certain visual objects in motion, is presented to a subject, who responds by moving in some way, e.g., touching a response target depending on what objects are displayed and/or how the objects move. For example, the subject may use a virtual reality system and motion sensors attached to the subject's arms or held in the hands. A variety of parameters may be determined, e.g., reaction time, accuracy, etc., which may be useful for assessing the subject's perceptual, cognitive, and motor functioning. In addition, in some embodiments, such tests may be given repeatedly, e.g., over several days, weeks, etc., to train or improve the subject's response.

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SYSTEMS AND METHODS FOR ASSESSMENT AND TRAINING OF PERCEPTUAL-MOTOR EFFICIENCY USING MOTION

RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Serial No. 63/390,619, filed July 19, 2022, entitled "Systems and Methods for Assessment and Training of Perceptual-Motor Efficiency Using Motion," incorporated herein by reference in its entirety.

FIELD

The present disclosure generally relates to systems and methods for assessment and/or training of brain function, for example, including neural processes associated with perceptual-motor efficiency.

BACKGROUND

Rapid and accurate responses to changing circumstances are important for managing a wide range of environmental interactions, including such activities as driving a vehicle or engaging in a competitive sport. Brain output does not necessarily involve serial processing of sensory inputs, but execution of an optimal response requires integration of neural information derived from somewhat segregated perceptual, cognitive, and motor processes. Very recent technological advances have dramatically increased our understanding of structural connectivity between defined populations of neurons (e.g., white matter tracts), as well as functional connectivity among spatially separated brain areas (e.g., temporally correlated activation patterns). For example, diffusion tensor imaging (DTI), functional magnetic resonance imaging (fMRI), magnetic resonance spectroscopy (MRS), electroencephalography (EEG), magnetoencephalography (MEG), transcranial magnetic stimulation (TMS), transcranial direct current stimulation (tDCS) and electromyography (EMG) have been used to identify neural correlates of numerous behavioral responses.

Brain networks are defined by both structural connections and functional activations that support specific neural processes, which may involve relatively isolated activity within a given network, or activity that is highly integrated with that of other networks. Structural connectivity may be necessary for transmission the of electrochemical signals from one area to another, but functional connectivity patterns reflect a complex balance of excitatory and inhibitory effects on signal transmission within both local and long-range neural circuits. Synchronization of oscillating neural signals (e.g., brainwaves) between spatially separated brain areas may also be important to information processing efficiency.

SUMMARY

Certain aspects such as discussed herein are generally directed to systems and methods for assessment and training of perceptual-motor efficiency using moving visual stimuli and reactive body movements. Some aspects, for instance, use congruent and incongruent trials. As discussed in more detail herein, discrimination tests and neural efficiency training involve presentation of different types of visual stimuli, which may include congruent and incongruent trials. For instance, in a congruent test trial, some aspect of the congruent stimulus corresponds to some feature of a response target, thereby providing a "cue" for execution of a correct response. If movement direction defines congruency, the correct body movement response is executed in the "same" direction as the motion of a congruent visual stimulus (e.g., a filled circle; white against black background). In contrast, in an incongruent test trial, the correct body movement response is executed in the "opposite" direction of the motion of a visual "cue" stimulus (e.g., an open circle; white border around black interior against black background), which is known to elicit activations of specific brain areas that resolve conflict.

Without wishing to be bound by any theory, it is believed that the speed and accuracy of responses to congruent and incongruent trials may be related to direct measurements of structural and functional connectivity within the anterior insula (AI) and the dorsal anterior cingulate cortex (dACC), which are important nodes of the salience network (SN). In some embodiments, "discrimination" reaction times may be determined as a technique to assess impulse control and/or the conflict resolution process associated with perceptual and cognitive interpretation of directional symbols. In some embodiments, the visuospatial nature of some of the tests described herein may be used to selectively assess information processing. In some cases, the responses to the stimuli may be simple button presses or the touching of suitable response targets that do not require complex motor activation patterns. In addition, in some cases, "dual-task" tests may be used that impose simultaneous cognitive and motor challenges, which may cause performance decrements in one or both tasks compared to performance of the respective tasks separately. In certain embodiments, whole-body movement responses to various types of stimuli may have greater relevance to functional activities.

Thus, certain embodiments are directed to certain tests that are applied to the subject, and the speed and/or accuracy of the subject's response can be determined. For example, the test may involve a discrimination task that uses both congruent and incongruent motion stimuli. A response of the subject (e.g., movement to the left or right), may be determined.

In some cases, presentation of a moving visual stimulus for measurement of reaction time may provide more sensitive detection of a subtle impairment than a static stimulus. In some cases, the reaction time in response to perceived movement onset of a visual stimulus may be associated with the timing of brain signals that that are processed by the V5/MT+ area, whereas the timing of supplementary motor area (SMA) activation does not appear to exert any substantial influence on the speed of a pre-specified muscle responses to the moving stimuli.

In some embodiments as discussed herein, reaction times such as functional reaction times may be determined. Functional reaction time may refer to a designation for measurements of the speed of different types of motive responses to visual stimuli that impose some level of cognitive challenge, which may require activation of the executive control network (ECN) for visual-spatial calibration and decision-making, and require translocation of the body mass. Without wishing to be bound by any theory, it is believed that the SN (AI and dACC) deactivates the default mode network (DMN) and activates the ECN, which includes the dorsolateral pre-frontal cortex (dlPFC) and superior parietal lobe (SPL). The ventral attention network (VAN), which includes the temporo-parietal junction (TPJ) and mid-frontal cortex (MFG) of the right hemisphere, may play an important role in detection of salient visual stimuli that engage the SN. The VAN also may convey information to ECN through the dorsal attention network (DAN), which includes the frontal eye field (FEF) and intra-parietal sulcus (IPS). Execution of a movement responses to visual stimuli may engage the somatosensory-motor network (SMN) to a variable extent, which can depend on the complexity of the required motor activation sequences. Important nodes of the SMN include the primary somatosensory cortex (S1), the primary motor cortex (M1), the premotor cortex (PMC), the supplementary motor area (SMA), and the cerebellum (CBM). The thalamus (TH) and basal ganglia (BG) play important roles as integration hubs that link visual, cognitive, and motor processes. The extent of activation of a given network node may depend on the precise nature of task. For example, activation of the CBM may be much greater for bilateral and multi-directional whole-body movements than unilateral extremity reaching motions in a standing position, or simple button presses in a seated position. Furthermore, some perceptual-motor responses may require inter-hemispheric transmission of neural signals for effective coordination of movements that can reveal asymmetries in performance capabilities. Thus, certain embodiments as discussed herein may be directed to systems for functional/discrimination reaction time measurement that combines detection of

visual stimulus movement direction (V5/MT+), impulse control and conflict resolution (AI, dACC), and execution of different types of motor responses.

Some embodiments such as those discussed herein are generally directed to virtual reality (VR) or augmented reality (AR) systems. For instance, use of a virtual reality or augmented reality headset for presentation of visual stimuli may offer the advantages of a standardized viewing distance and tracking of pupil or eye movements, in certain embodiments. An integrated representation of perceptual-cognitive-motor processing may be obtained through synchronous acquisition of data from an inertial measurement unit affixed to the body in some cases. In addition, in some cases, differing levels of simultaneous motor demand may be imposed by single-leg postural balancing, walking gait, lateral lunges, and/or lateral side-shuffling movements over a defined distance. In addition to reaction time and response accuracy, data derived from the inertial measurement unit may be used to assess postural jerk, asymmetrical body mass displacements during gait, acceleration, deceleration, or the like. In some embodiments, visual stimulus presentation on a display, combined with synchronous acquisition of accelerometer data, may allow for relatively unconstrained performance of various functional movement patterns. Metrics derived from such testing may, in certain cases, be compared to inertial measurement data obtained during unconstrained participation in physically demanding activity, which may establish the relevance of standardized test results to a subject's performance capabilities.

One feature of certain embodiments is the modification of difficulty for any given component of a combined perceptual, cognitive, or motor challenge. In some embodiments, relationships to known neural correlates may be used as indirect representations of the global processing efficiency of the various network subsystems engaged by specific combinations of visual, cognitive, and motor challenges. In certain cases, indirect identification of impaired neural processes may be achieved through non-traditional statistical analyses that may utilize measures of intra-individual variability and composite metrics, which may be linked to suboptimal synchronization of oscillatory neural signaling between networks or among the nodes of a given network. The limited accessibility and cost of the diagnostic technology required to acquire direct measures of brain structure and function make its use impractical for identification of individuals who might derive substantial benefit from targeted interventions for improvement of perceptual-motor efficiency. Thus, certain embodiments such as those discussed herein may be useful for the assessment and/or training of perceptual-motor efficiency in a typical clinical setting.

Accordingly, the present disclosure generally relates, in certain aspects, to systems and methods for determining brain function, including assessing and/or training perceptual-motor efficiency. The subject matter of the present disclosure involves, in some cases, interrelated products, alternative solutions to a particular problem, and/or a plurality of different uses of one or more systems and/or articles.

In one set of embodiments, the method comprises displaying, to a subject, a discrimination test and a plurality of response targets that appear to be at least 1 meter away from the subject; determining a response target of the plurality of response targets that the subject appears to touch in response to the discrimination test; and determining a reaction time and/or an accuracy of the subject in response to the discrimination test.

The method, in another set of embodiments, comprises (a) displaying, to a subject, a visual stimulus comprising either a first moving object or a second moving object, wherein the first moving object and the second moving object are visually distinct; (b) displaying, to the subject, a plurality of response targets that appear to be positioned to require the subject to take at least one step to reach; (c) determining which response target of the plurality of response targets the subject appears to touch in response to the visual stimulus comprising either the first moving object or the second moving object; (d) repeating (a)-(c) at least once; and (e) determining the subject's accuracy in touching the corresponding response targets in response to the plurality of displayed visual stimuli.

In yet another set of embodiments, the method comprises displaying, to a subject, a visual stimulus comprising a plurality of moving objects; displaying, to the subject, a plurality of response targets; determining a response target of the plurality of response targets that the subject appears to touch in response to the visual stimulus; and determining a plurality of reaction times, including at least two of: (a) a reaction time between the time the visual stimulus is displayed, and a response of the subject's eyes to the visual stimulus; (b) a reaction time between the response of the subject's eyes to the visual stimulus, and the time the subject begins moving towards one of the response targets; and (c) a reaction time between the time the subject begins moving towards one of the response targets, and the time the subject reaches the response target.

In another aspect, the present disclosure encompasses methods of making one or more of the embodiments described herein. In still another aspect, the present disclosure encompasses methods of using one or more of the embodiments described herein.

Other advantages and novel features of the present disclosure will become apparent from the following detailed description of various non-limiting embodiments of the disclosure when considered in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting embodiments of the present disclosure will be described by way of example with reference to the accompanying figures, which are schematic and are not intended to be drawn to scale. In the figures, each identical or nearly identical component illustrated is typically represented by a single numeral. For purposes of clarity, not every component is labeled in every figure, nor is every component of each embodiment of the disclosure shown where illustration is not necessary to allow those of ordinary skill in the art to understand the disclosure. In the figures:

Fig. 1 illustrates various congruency tests, in accordance with certain embodiments;

Fig. 2 illustrates a device for conducting tests such as congruency tests, in accordance with one embodiment;

Fig. 3 illustrates a VR device, in another embodiment;

Figs. 4A and 4B illustrate data visualizations of the responses of two individuals to certain test stimuli, in accordance with certain embodiments;

Figs. 5A-5D illustrate certain congruency tests, in accordance with some embodiments;

Fig. 6 illustrates a VR image implementing a congruency test, in still another embodiment; and

Fig. 7 illustrates an interaction between VR test performance (e.g., inconsistency among responses following discrimination between congruent and incongruent visual stimuli) and self-rated impact of various health-related conditions (e.g., Sport Fitness and Wellness Index score) for identification of individuals with remote history of concussion in yet another embodiment.

DETAILED DESCRIPTION

The present disclosure generally relates to systems and methods for assessment and training of brain function, specifically processes associated with perceptual-motor efficiency. In certain aspects, a discrimination task, or other perceptual-motor tasks involving certain visual objects in motion, is presented to a subject, who responds by moving in some way, e.g., touching a response target depending on what objects are displayed and/or how the objects move. For example, the subject may use a virtual reality system and motion sensors attached to the subject's arms or held in the hands. A variety of parameters may be

determined, e.g., reaction time, accuracy, etc., which may be useful for assessing the subject's perceptual, cognitive, and motor functioning. In addition, in some embodiments, such tests may be given repeatedly, e.g., over several days, weeks, etc., to train or improve the subject's response. In some cases, the tests may adaptively increase in difficulty, e.g., on the basis of the subject's preceding performance. Other aspects as discussed herein are generally directed to devices or kits for conducting such tests, methods of using such tests, and the like.

Certain aspects are generally directed to systems and methods for assessing and/or training perceptual-motor efficiency in a subject, such as a human subject. For example tests such as congruency tests or other perceptual-motor tests, may be administered to a subject. In one set of embodiments, a visual stimulus comprising a plurality of objects is displayed to the subject, for example, on a display in a virtual reality or an augmented reality system. Optionally, a focal point is also displayed to the subject, e.g., before displaying a plurality of objects. The objects that are displayed may independently appear to be the same or different, and/or appear in the same or different locations. In some cases, the plurality of objects within the visual stimulus may include one or more objects that move and/or one or more objects that do not move. The subject may be asked to move in response to the visual display, for example, to touch one or more response targets. For example, the subject may be asked to move in a first direction in response to a first object (e.g., moving in certain direction) and a second direction in response to a different type of object (e.g., moving in a certain direction). Other examples of object motion are discussed in more detail herein.

In some cases, the response targets may appear to be positioned at some distance away from the subject, e.g., to cause the subject to need to move significantly in order to reach the response targets, for example, by taking one or more steps towards the response target. For example, the response targets may appear at least a meter away from the subject, thereby requiring the subject to take at least one step in order to touch the response target, or otherwise shift their body mass towards the response target.

In one set of embodiments, one or more motion sensors may be used to determine motion of the subject, e.g., towards a response target, and/or to determine that the subject has touched one of the response targets. A variety of motion sensors may be used, e.g., attached to the subject, or positioned externally of the subject (for example, a camera). For example, the subject may have one or two motion sensors attached to the subject's arms, wrists, hands, trunk, lower extremities, legs, feet, etc., which can be used to determine motions of the subject's body segments.

The performance of the subject may be determined, e.g., reaction time, accuracy, or other suitable metrics. For example, if a subject is expected to touch a first response target or a second response target in response to a visual stimulus, then performance metrics such as accuracy (e.g., of the subject touching the correct response target) and/or reaction time (e.g., the time between when the visual stimulus is presented and the time the subject touches a response target) may be determined. In addition, in some cases, other metrics may be determined as well. For instance, in one embodiment, the spatial accuracy of the subject's touching of a response target may be determined. In another embodiment, the smoothness of the gait or motion of the subject towards a response target may be determined.

In some cases, more than one reaction time may be determined. For instance, in some cases, various reaction times that may be determined include, but are not limited to, the time between the visual stimulus and a response of the subject's eyes to the visual stimulus, the time between the response of the subject's eyes to the visual stimulus and when the subject starts moving, the time between when the subject starts moving and when the subject touches the response target, or the like. In addition, in some cases, depending on the presence or absence of impairment of brain function, performance metrics may be affected by mental and/or physical fatigue due to prolonged testing (e.g., averaged values for the second half of a test may differ from those demonstrated during the first half of a test).

In some embodiments, multiple such tests may be administered to a subject. For example, a subject may be exposed to series of tests to determine overall reaction times, accuracy, etc. for the subject. In addition, in certain cases, one or more such tests may be given on different days or at different times, or spaced apart by a minimum time, etc. For example, such tests may be used to determine if there is any change to a subject (e.g., the perceptual-motor efficiency of the subject), for example, if the subject has a neurological condition. Examples of neurological conditions include, but are not limited to, dementia, Parkinson's Disease, Alzheimer's Disease, stroke, concussion, ADHD, or the like. As another non-limiting example, the tests may be used to improve or train the subject. For instance, in certain cases, a subject may be administered such tests to improve the subject's hand-eye coordination, reaction time, athletic performance, or the like over time.

In addition, in certain cases, the difficulty of the tests may be adaptively increased over time, for example, if the subject exhibits improved performance (e.g., of the neurological condition, of athletic fitness, of reaction time, etc.). In some cases, the difficulty may be increased linearly, although in other cases, the difficulty may be increased in response to a subject's performance (for example, if the subject achieves a certain accuracy, reaction

time, or the like), or the difficulty may be increased based on other criteria or performance metrics. For instance, the difficulty may be increased by changing the number of objects (moving and/or fixed), the appearance of the objects (e.g., size, shape, color, etc.), the amount of time the subject has to touch a response target, the lighting of the objects, the position of the objects, or the like. In addition, in certain cases, the difficulty may be increased based on the positioning of objects, e.g., towards or at the peripheral limit of the useful field of view.

Additionally, in certain embodiments, the tests may be "gamified," e.g., with a score presented to the subject based on the subject's performance. In some cases, such scores may be compared to other subjects, e.g., as a competitive measure. For example, different subjects may compete to see who can achieve the highest difficulty levels the quickest, or achieve the highest score, etc.

One non-limiting example of such a test is now described, in accordance with certain aspects. A task may include a single choice between options that is followed by others, for example, a single repetition, while a test describes a series of successive choices, e.g., as identified by a specified number of repetitions. Referring now to Fig. 1, a plurality of objects is shown to a subject, e.g., on the display of a VR device. The objects may independently be stationary and/or may move during a test. The subject is to touch a response target depending on how the objects move. The response targets may also be shown on the display, i.e., the response targets may be virtual. As shown here, the response targets are positioned such that the subject has to move to reach a response target, for instance, by having to take one or more steps towards the response target, or otherwise shift their body mass towards the response target. Movement of the subject may be determined, for instance, using one or more motion sensors. These may be held or worn by the subject, and/or positioned externally of the subject, etc. In a virtual display, the objects and the response targets may each independently take on a variety of shapes, colors, sizes, locations, etc., depending on the type of test to be administered. For instance, as is shown in Fig. 1, these are shown as

The above discussion is a non-limiting example of one embodiment of the present invention that can be used to assess and/or train perceptual-motor efficiency in a subject. However, other embodiments are also possible. Accordingly, more generally, various aspects of the invention are directed to various systems and methods for assessment and/or training of a subject.

For example, some aspects are generally drawn to tests that use one or more visual stimuli that comprise a plurality of objects. The plurality of objects may be real objects, and/or they may be a projection of an object on a display, e.g., in a virtual reality or an

augmented reality system, or other display (e.g., a smartphone). The objects may have any appearance. In addition, in some embodiments, some or all of the objects may have a relatively small size, e.g., such that its apparent position, as observed by the subject, is known to a relatively high degree of precision. In some cases, the objects within the visual stimulus may include one or more objects that move and/or one or more objects that do not move.

The objects that are displayed may independently appear to be the same or different, and may each independently have any shape or color. For example, an object may appear to be a circle, a ball, or a sphere. As other examples, an object may be a square, a triangle, a diamond, a cube, a block, a cylinder, a tetrahedron, a polyhedron, or appear to be a flat shape or a real object, etc. The object may have a single color, or exhibit a range of colors. In addition, in some embodiments, the object may change its appearance (e.g., luminance or oscillatory motion) and/or size, etc., for example, as a function of time or position, etc. Such differences among multiple objects may serve as "cues" for the locations of response targets, which will permit assessment of anticipatory neural processes.

As a non-limiting example, an object may appear to be a circle, a ball, or a sphere that has a diameter of between 10 mm and 20 mm, and may be presented to appear at a distance of between 0.8 m and 1.2 m from the subject. However, it should be understood that this is by way of example only, and that an object may be larger or smaller, and/or may appear closer or farther away from the subject. In addition, in some cases, the object may grow or shrink in size (e.g., such that the object appears to go closer to or farther away from the subject).

For instance, an object may appear to be at least 10 cm, at least 20 cm, at least 50 cm, 100 cm, at least 200 cm, at least 500 cm, at least 700 cm, at least 1 m, at least 1.3 m, at least 1.5 m, at least 2 m, at least 3 m, at least 5 m, at least 10 m, etc. from the subject, and/or the tracking object may appear to be no more than 10 m, no more than 5 m, no more than 3 m, no more than 2 m, no more than 1.5 m, no more than 1.3 m, no more than 1 m, no more than 700 cm, no more than 500 cm, no more than 200 cm, no more than 100 cm, no more than 50 cm, no more than 20 cm, no more than 10 cm, etc. Combinations of any of these are also possible, e.g., an object may appear to be between 10 m and 15 m, between 50 cm and 100 cm, between 700 cm and 1 m, etc., from the subject. An object may appear to stay a constant distance from the subject, and/or an object may have a trajectory where it appears to move closer and/or farther away from the subject.

In addition, an object may appear to be of any size. For example, an object may appear to have a maximum dimension of at least 2 mm, at least 3 mm, at least 5 mm, at least

7 mm, at least 10 mm, at least 20 mm, at least 30 mm, at least 50 mm, at least 70 mm, at least 100 mm, at least 200 mm, at least 300 mm, at least 500 mm, at least 700 mm, at least 1 m, etc. An object may also appear to have, in certain embodiments, a maximum dimension of no more than 1 m, no more than 700 mm, no more than 500 mm, no more than 300 mm, no more than 200 mm, no more than 100 mm, no more than 70 mm, no more than 50 mm, no more than 30 mm, no more than 20 mm, no more than 10 mm, no more than 7 mm, no more than 5 mm, no more than 3 mm, no more than 2 mm, etc. Combinations of any of these dimensions are also possible. As a non-limiting example, an object may appear to have a maximum dimension of between 10 mm and 20 mm, between 200 mm and 300 mm, between 3 mm and 10 mm, etc.

As mentioned, more than one object may be present, and the various objects may independently be stationary or may move. If an object moves, it may do so on any suitable trajectory. In one set of embodiments, the trajectory may be linear. In other embodiments, the trajectory may be nonlinear, e.g., circular, spiral, random, or the like. The object may also move at any suitable speed. For instance, the object may move at an apparent speed of at least 0.01 m/s, at least 0.02 m/s, at least 0.03 m/s, at least 0.05 m/s, at least 0.1 m/s, at least 0.2 m/s, at least 0.3 m/s, at least 0.5 m/s, at least 1 m/s, at least 2 m/s, at least 3 m/s, at least 5 m/s, at least 10 m/s, etc. The object may also move at an apparent speed of no more than 10 m/s, no more than 5 m/s, no more than 3 m/s, no more than 2 m/s, no more than 1 m/s, no more than 0.5 m/s, no more than 0.3 m/s, no more than 0.2 m/s, no more than 0.1 m/s, no more than 0.05 m/s, no more than 0.03 m/s, no more than 0.02 m/s, no more than 0.01 m/s, etc. Combinations of any of these are also possible; for example, an object may move at an apparent speed of between 1 m/s and 2 m/s, between 0.05 m/s and 3 m/s, between 2 m/s and 10 m/s, or the like. The speed of an object may be constant, or may vary in some instances.

The object may follow the trajectory for any suitable length of time and/or distance, e.g., before disappearing from the field of view. For instance, the object may follow a trajectory, such as a linear trajectory, for at least 5 seconds, at least 10 seconds, at least 15 seconds, at least 20 seconds, at least 25 seconds, at least 30 seconds, at least 40 seconds, at least 45 seconds, at least 50 seconds, at least 1 minute, at least 1.5 minutes, at least 2 minutes, at least 3 minutes, at least 4 minutes, at least 5 minutes, etc.

In certain aspects, the objects may have trajectories based on one or more tests administered to the subject. For example, the tests may include one or more perceptual-motor tests. Various tests such as those described herein may be used to assess or train perceptual-motor efficiency in a subject. For example, certain tests may include the display

of one or more moving objects, and require the subject to respond in some way based on the appearance of a designated object and/or how the objects move. For instance, the subject may be required to touch one of a number of response targets based on the trajectories of the objects. Without wishing to be bound by any theory, it is believed that such tests may be useful, for example, to assess and/or to train the perceptual-motor efficiency of a subject. In addition, in some cases, the specific types of demands that are imposed may promote specific neuroplastic adaptations in brain structure and function.

In some cases, the tests may measure various reaction times of the subject. Such reaction times generally measure the reaction of a subject to a visual display. For example, the test may include determinations of the time between the visual stimulus (e.g., involving one or more moving objects) and a response of the subject's eyes to the visual stimulus, the time between the response of the subject's eyes to the visual stimulus and when the subject starts moving towards a response target, the time between when the subject starts moving and when the subject touches the response target, etc. As discussed herein, a variety of sensors may be used to determine such reactions times.

The subject's motions, actions, positioning, etc. may be determined using one or more motion sensors. In some cases, a motion sensor may be attached to the subject, e.g., to a subject's hands or arms. In certain embodiments, a motion sensor may be external to the subject. More than one motion sensor may be used in some instances. In some cases, the motion sensors may be used to determine whether the subject is touching or is reaching towards a response target, etc. For example, the motion sensors may be used to determine whether the subject has moved, e.g., in a certain direction, and/or whether the subject has touched the correct response target, e.g., in response to a discrimination trial. In addition, in some case, the motion sensors may be used to determine a subject's position, e.g., in a room, or relative to a response target, etc.

Thus, if response targets are present (e.g., for the subject to touch), the response targets may remain stationary in position and/or appearance, or the response targets may change appearance or even move, e.g., between and/or during a test. Like objects, the response targets may have a variety of appearances. The response targets may be visually similar or dissimilar to the objects, and may have the same descriptions as those given herein for various types of objects, e.g., having any size, shape, color, appearance, etc.

In some cases, the response targets may be positioned at a relatively far distance away from the subject, e.g., such that the subject will need to take one or more steps in order to touch a response target, or otherwise shift their body mass towards the response target. For

instance, the response targets may be at least 0.5 m, at least 0.75 m, at least 1 m, at least 1.5 m, at least 2 m, etc. away from a subject. In some embodiments, the response target's location may correspond to a distance that is proportional to the subject's physical stature (e.g., height or wingspan). There may be 1, 2, 3, 4, 5, or more response targets presented to a subject. As a non-limiting example, there may be two response targets, one on the left of the subject and one on the right of the subject. The subject thus would need to move leftward or rightward to touch the corresponding response target. A variety of different response targets may be presented, e.g., depending on the type of test administered to the subject.

In addition, in some embodiments, the subject may be presented with a focal point, e.g., that the subject is to focus on, prior to a test or other visual stimulus. In certain cases, one or more eye tracking sensors may be used to determine whether the subject is visually focusing on the focal point before a test can begin. Eye tracking sensors are discussed in more detail herein.

A focal point presented to a subject may have any suitable appearance. For instance, the focal point may be visually similar or dissimilar to the objects, and may have the same descriptions as those given herein for various types of objects, e.g., having any size, shape, color, appearance, etc. In some cases, the focal point may be useful to ensure that the subject's eyes are positioned in a standardized location prior to the display of objects. In addition, in some embodiments, the focal point may be useful to provide a cue to the direction from which a moving visual stimulus may imminently appear from a position beyond the subject's peripheral field of view.

As mentioned, certain aspects are generally directed to assessing and/or training perceptual-motor efficiency in a subject, for example, using perceptual-motor tests involving certain objects in motion where a subject has to respond by moving in some way, e.g., touching a response target depending on what objects are displayed and/or how the objects move. One non-limiting example of such a test is a discrimination test. In a discrimination test, a visual stimulus is presented to a subject, that includes a plurality of objects that require an understanding of congruency or incongruency in order to properly respond. For example, in some embodiments, the objects that are presented may be visually congruent in some way, e.g., the objects may be substantially identical or compatible, such as a series of arrows that all point the same direction. As discussed herein, congruency involves consistency of some characteristic(s) of a stimulus with a correct response. More complex discrimination tasks may involve perception of additional features that provide cues about correct responses. However, the objects that are presented may also be visually incongruent in some way, e.g.,

one of the objects may be different than the other objects, for example, a series of arrows where one points in the opposite direction.

As another example, in a congruency test involving objects in motion, a subject may be asked to perform a motion (for example, moving towards a response target) that is congruent to an object's motion (i.e., where the subject is to move in the same or congruent direction as the object's motion), or to perform a motion that is incongruent to an object's motion (i.e., where the subject is to move in the opposite or incongruent direction as the object's motion). The type of test (congruent or incongruent) may be indicated, for example, by using two or more visually distinct objects. As a non-limiting example, a first object (for example, a filled circle) may be used to indicate that the subject is to congruently move in the direction of the first object, while a second object that is visually distinct in some way (e.g., an open circle, a differently-colored circle, a different shape such as a square, etc.) may be used to indicate that the subject is to incongruently move in a direction opposite to the direction of the second object. Thus the objects may be visually distinct for any of a number of reasons, including color, size, shape, position, distance, etc., as discussed herein. As another example, the objects may have a marking or a character (e.g., a "+" or a star, etc.) to make them visually distinct.

The subject may be instructed to touch one of several possible response targets based on the direction (or the opposite of the direction) that an object moves, depending on the type of discrimination test that is applied. For instance, in a discrimination test, an object may move substantially horizontally, and/or at an angle relative to horizontal (for example, at an angle of between +/- 45°, between +/- 35°, between +/- 30°, between +/- 25°, between +/- 20°, between +/- 15°, between +/- 10°, or between +/- 5° relative to the horizontal, for example, such that the object is readily identifiable as moving either left or right. The subject may respond, for example, by moving congruently (either left or right in the same direction that the object is moving), or by moving incongruently (either left or right in the same direction that the object is moving), for example, based on the appearance of the object. Furthermore, the precise location of a response target may correspond to position on the angular path of a designated moving object.

As a specific non-limiting example, in the sample discrimination tests shown in Fig. 1, Level 1, there may be two response targets presented to a subject, one to the left and one to the right of the subject. The subject may be exposed to a visual stimulus (optionally with a preceding focal point, e.g., to alert and/or orient the subject). Thus, in this example, if the subject sees a filled circle on a display, thereby indicating a congruent stimulus, the subject is

to touch the response target based on the filled circle's motion (i.e., if the filled circle is moving to the left, the subject is to touch the response target on the left, and if the filled circle is moving to the right, the subject is to touch the response target on the right). As illustrated in this figure, the direction of the visual stimulus is shown with a solid arrow, while the direction the subject should move to reach the correct response target is shown with a dashed arrow. In contrast, if the subject sees an open circle, indicating an incongruent test, the subject is to touch the response target in the direction opposite to the open circle's motion (i.e., if the open circle is moving to the left, the subject is to touch the response target on the right, and if the open circle is moving to the right, the subject is to touch the response target on the left).

It should be noted that the discrimination tests can be increased in difficulty, for example, by addition additional objects around the objects that move, thereby distracting or confusing the subject and increasing the difficulty of the test. For example, the objects may be stationary and not move, and/or some of the objects may move. The objects may be positioned around the visual stimulus, e.g., that the subject is responding to. Non-limiting examples include those shown in Levels 2-5 of Fig. 1. It should be noted that the difficulty can be increased, for example, stepwise, in response to a subject's reaction times or accuracy, or due to other factors (e.g., beating a previous record by the subject or by others). A variety of different types, numbers, positions, etc. of other objects may be displayed to the subject to increase the difficulty of the tests, such as the specific non-limiting examples that are shown in Levels 2-5. For example, in some cases, multiple moving objects may be displayed after the focal point disappears to increase the difficulty.

In addition, in some embodiments, multiple tests can be executed, and information about the subject in response to those tests determined. For example, a plurality of discrimination tests may be administered, including tests involving congruent stimuli and incongruent stimuli. These may be presented to the subject in any suitable order, e.g., randomly so as to prevent the subject from anticipating the correct motions to take. For instance, at least 10, at least 15, at least 20, at least 25, at least 30, at least 40, at least 50, at least 75, at least 100, etc. tests, such as congruency tests, or other perceptual-motor tests, may be applied to a subject, e.g., in a single test session.

The subject's accuracy to tests such as these may be determined, for example, as the accuracy of touching the correct response target in response to a presented test (e.g., did the subject touch the congruently positioned response target in response to a congruent test and the incongruently-positioned response target in response to an incongruent test). As another

example, the accuracy of the subject's touching of a response target in response to a test (for example, the accuracy of the subject's hand in touching a response target) may be determined. In some cases, the accuracy may be reported as percentage (e.g., the percent of tests where the subject touched the correct response target), although in some cases, other methods may be used (e.g., the scoring of arbitrary points, as in a game).

In addition, in certain embodiments, a subject may be asked to perform a physical task while simultaneously engaged in a cognitive activity, e.g., a "dual-task" test. Non-limiting examples of cognitive tasks include, but are not limited to, counting numbers in some fashion (e.g., counting forwards, counting backwards to 100, counting backwards in steps of 7), reciting multiplication tables, identifying songs being played in the background, reciting state or country names, or the like. For instance, such tasks may be performed by the subject (or attempted to be performed) while the subject is also taking one or more tests such as those described herein, e.g., discrimination tests.

Without wishing to be bound by any theory, it is believed that a subject who attempts to carry out multiple actions at once may experience some degree of neural interference due to competition among perceptual, cognitive, and motor processes for access to a finite amount of neural resources. This may be useful, for example, to identify the underlying neural impairment that is responsible for a subtle performance deficiency.

In some cases, the subject's reaction time in response to the tests may be determined, e.g., in addition or instead of determining accuracy. For example, one reaction time that may be determined is the time between when a visual stimulus is presented (e.g., involving one or more moving objects) and a response of the subject's eyes to the visual stimulus (for example, as determined by one or more eye tracking sensors such as described herein). As another example, another reaction time that may be determined is the time between the response of the subject's eyes to the visual stimulus and when the subject starts moving towards a response target (for example, as determined by one or more motion sensors such as described herein). As yet another example, a reaction time that may be determined is the time between when the subject starts moving and when the subject touches the response target, etc.

Without wishing to be bound by any theory, it is believed that such reaction times may be indicative of certain perceptual, cognitive, and motor processes in a subject. As mentioned, such perceptual, cognitive, and motor processes are somewhat segregated within the brain. Accordingly, tests that rely on such processes may be used to assess a subject, e.g., the mental functioning of the subject, or the subject's perceptual-motor efficiency. In some

embodiments, for example, a significantly longer reaction time compared to other reaction times in the same subject may indicate a deficiency in the subject's ability to integrate perceptual, cognitive, and motor processes. This may be used, for example, as a baseline measurement of the subject's mental status, and/or there may be some intervention or treatment of the subject (e.g., therapy, pharmaceuticals, counseling, etc.) as a result of such tests.

As mentioned, a plurality of tests may be administered to the subject in accordance with certain aspects. These may be applied all at once, and/or a variety of test sessions (each comprising one or more tests) may be administered to the subject over an extended period of time. This may be useful, for example, to train or improve the athletic performance of a subject, to assess whether a subject having a neurological condition is improving or not, etc. (for example, in response to therapy or intervention, etc.) For example, a plurality of test sessions may be administered on a daily basis (or at least 12 hours apart), on a weekly basis, or the like.

As discussed, in some aspects, the tests may include visual stimuli that can be presented using a variety of equipment. As a non-limiting example, a plurality of objects may be presented as visual stimuli to a subject, e.g., using a display. In addition, in some cases as discussed herein, the eye positions of the subject are detected using one or more eye tracking sensors. These may be controlled, for example, using a processor.

A non-limiting example schematic figure of such a system is shown in Fig. 2. In this figure, system 10 is used to test a subject, e.g., as a human subject. The subject is shown a display 20, upon which an object 25 is shown. The object may appear to be stationary or moving, e.g., in trajectories such as those discussed herein. In addition, more than one object may be present in some embodiments. The display may be, for example, a display on a VR headset, an external monitor, a display on the smartphone, or the like, e.g., as discussed herein. In some embodiments, eye tracking sensor 30 can be used to track the position of eyes 60 of the subject. In this non-limiting example, the sensor includes a light source 32 and a camera 35 that records light 37 passing between light source 32 and camera 35. The angle of deflection of the light may be used to determine where the eyes are focused. This may be used, for example, to determine a reaction time between the time an object is displayed, e.g., as part of a test, and/or a response of the subject's eyes to the test. However, it should be understood that eye tracking sensors are not necessarily required in all embodiments. In addition, a processor 50 may be used to produce images on display 20 and/or track eye movements via eye tracking sensors 30.

In addition, in some cases, the components shown in Fig. 2 can be contained within a headset such as a VR headset, for example, one that can be worn by a subject as is shown in Fig. 3. In general, VR headsets can be readily obtained commercially; non-limiting examples include Oculus Quest 2, Sony PlayStation VR, HP Reverb G2, or the like. The headset may contain therein a display that can be viewed by the subject, and optionally one or more eye tracking sensors. A processor may also be present within the headset, and/or located externally of the headset (for example, in wired or wireless communication with the headset). For example, the headset may be able to send and/or receive signals with a processor that is external to the headset. As another example, the headset may be self-contained, e.g., able to conduct a test on a subject without requiring any additional controls.

The device may be any suitable device. For example, the device may be a room-sized device, a VR (virtual reality) system, a headset (e.g., a VR headset), or the like. The device may include a variety of displays, eye tracking sensors, processors, and/or other components, etc., in various embodiments. Displays, VR systems, headsets, and other similar components may also be obtained commercially. In other examples, the device can include a frame that permits a subject to rest their head within the framework to observe the display. In yet another embodiment, one or more sensors can be placed throughout the framework or device to provide measurements of subject's system movement and/or position, etc.

For example, in one set of embodiments, the device may include a display for displaying an image of an object to be tracked. The display may be a single screen, or may comprise two or more screens (for example, one for each eye). The display may be provided with instructions (e.g., from a processor) to display an image or a sequence of image frames, e.g., such that an object shown the display appears to move (for example, as discussed herein). In some cases, a magnifying lens may be position between the display and the subject's eyes. The display may be any suitable display for producing an image, for example, LED displays, CRT displays, LCD displays, or the like.

The device may also include one or more eye tracking sensors for tracking the eyes. Any of a variety of eye tracking sensors may be used, many of which can be obtained commercially. For instance, in one set of embodiments, the eye tracking sensor may comprise an illumination source, such as an infrared or near-infrared light-emitting diode (LED) configured to illuminate an eye with light, and one or more sensors configured to detect the light reflected by the eye. For example, the sensors may include cameras, search coils, electrooculograms (for potential measurement), etc. Other examples include video-based tracking sensors, infrared red, near infrared, and passive light sensing, etc. In some

embodiments, the sensors may be built into glasses or other devices (e.g., VR headsets, etc.), including any of those described herein.

The sensors may, in some embodiments, capture or sample at relatively high frequencies, e.g., at least 30 Hz, at least 40 Hz, at least 50 Hz, at least 60 Hz, at least 100 Hz, at least 240 Hz, at least 350 Hz, at least 500 Hz, at least 1000 Hz, at least 1250 Hz, at least 2000 Hz, etc. In some cases, the sensors may operate without the use of an illumination source. In addition, other optical methods may be used in other embodiments.

In some embodiments, a processor is used to produce images on the display and track eye movements via one or more eye tracking sensors. For example, the processor may include any of various types of circuits and/or computing devices. These may include one or more processors and/or non-transitory computer-readable storage media (e.g., memory, non-volatile storage devices, etc.). The processor may control writing data to and/or reading data from memory, and/or non-volatile storage devices. The processor can be a programmed microprocessor or microcomputer, which can be custom made or purchased from computer chip manufacturers. To perform any of the functionality described herein, the processor may execute one or more processor-executable instructions stored in one or more non-transitory computer-readable storage media, which may serve as non-transitory computer-readable storage media storing processor-executable instructions for execution by the processor.

It should be understood that the present disclosure is not limited to only VR systems. In another set of embodiments, for example, the device may be a smartphone. In some cases, for instance, the smartphone may contain a camera (which can be used as an eye tracking sensor), a display (which can be used to display an object to be tracked), and a processor. For example, the smartphone may be held such that a built-in camera within the smartphone faces the user while the user views the display of the smartphone, e.g., such that the camera can be used to track the user's eyes. In addition, in certain embodiments, the smartphone may be connected to an external camera and/or an external display, i.e., instead of and/or in addition to using a built-in camera and/or display on the smartphone. The processor may be programmed to produce images on the display and/or track eye movements via the camera (e.g., used as an eye tracking sensor), for example, as discussed herein.

In yet another set of embodiments, the device may be a computer, e.g., a desktop computer or a laptop computer. In certain cases, the computer may be connected to an external camera, and/or contain a built-in camera, which can be used as an eye tracking sensor, e.g., as discussed herein. such that the camera can be used track the user's eyes. The computer may also be connected to an external display, and/or contain a built-in display, for

example, which can be used to display an object to be tracked. In some embodiments, the camera may be positioned such that the camera is able to image the user's eyes while the user views the display. The computer may also contain a processor, e.g., which may be programmed to produce images on the display and/or track eye movements via a camera (for example, used as an eye tracking sensor), such as discussed herein.

In some embodiments, the device may be positioned on a stationary object, e.g., a table or a counter. However, in other embodiments, the device may not necessarily be stationary. For example, the device may be a smartphone that is held by the user. In some embodiments, positioning or motor corrections may be applied to the program, e.g., by incorporating sampling gyroscope or accelerometer data from the device in order to correct for the position of the device in order to track the user's eyes and/or track motion of the display, etc.

The terms "program" or "software" are used herein in a generic sense to refer to any type of computer code or set of processor-executable instructions that can be employed to program a computer or other processor (physical or virtual) to implement various aspects as discussed herein. Additionally, according to one embodiment, one or more computer programs that when executed perform methods of the disclosure provided herein need not reside on a single computer or processor, but may be distributed in a modular fashion among different computers or processors to implement various embodiments of the disclosure provided herein.

Processor-executable instructions may be in many forms, such as program modules, executed by one or more computers or other devices. Generally, program modules include routines, programs, objects, components, data structures, etc. that perform tasks or implement abstract data types. Typically, the functionality of the program modules may be combined (e.g., centralized) or distributed.

Other components that may be present within the device include, but are not limited to, a power supply (which may be rechargeable), an antenna, a radio frequency (RF) receiver and/or transmitter, analog to digital convertors, a real time clock, etc. For example, the antenna can be used to send and/or receive signals from an external device, such as a laptop, mobile device, computer, etc. This may be used, for example, to control operation of the device, transmit data to or from the device, modify operational parameters of the device, or the like.

U.S. Provisional Patent Application Serial No. 63/390,619, filed July 19, 2022, entitled "Systems and Methods for Assessment and Training of Perceptual-Motor Efficiency Using Motion," is incorporated herein by reference in its entirety.

The following examples are intended to illustrate certain embodiments of the present disclosure, but do not exemplify the full scope of the disclosure.

EXAMPLE 1

In this example, a 4-week training program designed with the goal to improve perceptual-motor performance consisted of 1-3 training sessions per week, which was initiated after the conclusion of a 4-week pre-season practice period. Each training session involved 2 sets of 20 lower extremity lunging movements in left or right directions, which were executed in response to white visual stimuli presented against a black background on a laptop computer monitor. The visual "cue" stimulus for a given trial was either a solid white circle or an open circle with a white outline that appeared at the center of the screen and moved horizontally in either a left or right direction beyond the screen margin within 500 milliseconds. The interstimulus interval was 1 second for all trials. Participants were instructed to execute a rapid lateral lunging movement in the same direction as the motion of a filled circle and in the opposite direction of the motion of an open circle. Whenever a participant demonstrated 95% response accuracy (19 or more correct out of 20 trials), the task difficulty was increased by the introduction of additional filled or open circles that flanked the "designated "cue" stimulus circle, thereby creating distracting motions on the screen. A total of 6 levels of task difficulty were used in this example.

The second level of task difficulty presented flanking distractor circles above and below the central cue stimulus circle, thereby creating a 3-circle column immediately prior to initiation of conflicting horizontal motions. A third level of task difficulty presented flanking circles to the left and the right of the central cue stimulus circle, thereby creating a 3-circle row immediately prior to initiation of overlapping horizontal circle motions in left and right directions. A 5-circle configuration that included a center cue stimulus circle with flanking circles placed above, below, left, and right provided fourth level of difficulty, which also presented a combination of horizontal and diagonal circle motions in left and right directions. Regardless of whether the cue stimulus circle motion was horizontal or diagonal, the participant executed a left or right lateral lunging movement of the lower extremity according to the stimulus-response instruction for a filled versus an open cue stimulus circle at the center of the 5-circle display. The fifth difficulty level designated the cue stimulus circle with a cross at its center, which randomly appeared in any one of the 5-circle display positions

from one trial to the next. For difficulty levels 1-5, the single-circle (level 1), 3-circle column (level 2), 3-circle row (level 3), or 5-circle display (levels 4 and 5) appeared at the center of the screen immediately prior to motion. The sixth difficulty level randomly presented the 5-circle display centered within either the upper-left, lower-left, upper-right, or lower-right quadrant of the tablet screen, along with the requirement to locate the cue stimulus circle containing a cross at its center as adjacent unmarked filled or open circles moved in overlapping horizontal or diagonal paths across the screen in left or right directions.

The tests used in this example are shown in Fig. 1. In this figure, the solid arrows indicate the direction the objects move; the dashed arrows indicate the direction the subject is to move to reach a response target. A moving filled object (e.g., a circle) indicates that the subject is to move in the direction that the object moves, while an open filled object indicates that the subject is to move in the direction opposite to that the object moves. The test can increase in difficulty in a number of different ways, such as by adding additional objects that do not move (which may, for example, also be solid or open), or having the subject identify a marked object amongst other similar objects that are not marked. In some cases, the unmarked objects may also move.

EXAMPLE 2

This example illustrates a series of difficulty levels for improve perceptual-motor performance as discussed in Example 1. These are schematically shown in Fig. 1.

Level 1:

Central fixation cross disappears, and single circle appears (filled or open) in middle of screen and rapidly moves horizontally across screen in left or right direction.

Subject instructed to execute a lateral lunge step in same direction as movement of filled circles and in opposite direction to movement of open circles.

Level 2:

Central fixation cross disappears, and “cue” stimulus circle appears (filled or open) in middle of screen, along with upper and lower flanking circles (filled or open) that may move in either the same direction as the cue stimulus circle or act as a distractor by moving in opposite direction above and/or below the motion of the central cue stimulus circle of the 3-circle column.

Subject instructed to execute a lateral lunge step in same direction as movement of filled circles and in opposite direction to movement of open circles.

Level 3:

Central fixation cross disappears, and "cue" stimulus circle appears (filled or open) in middle of screen, along with left and right flanking circles (filled or open) that may move in either the same direction as the cue stimulus circle or act as a distractor by moving in opposite direction.

Oppositely-directed motion of one or both flanking circles with that of the central cue stimulus circle of the 3-circle row creates an "overlapping" distraction that is more challenging than that created by the 3-circle column (Level 2).

Subject instructed to execute a lateral lunge step in same direction as movement of filled circles and in opposite direction to movement of open circles.

Level 4:

Central fixation cross disappears and "cue" stimulus circle appears (filled or open) in middle of screen, along with upper and lower flanking circles (filled or open) and left and right flanking circles (filled or open), any of which may move in either the same direction as the cue stimulus circle or act as distractors by moving in an opposite directions to that of central cue stimulus motion. Any of the circles (cue or flanking) may move horizontally or diagonally across screen in left or right directions.

Regardless of whether cue stimulus circle moves horizontally or diagonally, the subject is instructed to execute a "lateral" lunge step in a left or right direction that corresponds to the general direction of the cue stimulus circle.

Oppositely-directed motion of vertical and/or horizontal flanking circles with that of the central cue stimulus circle of the 5-circle (column + row) configuration creates multiple distractions that impose greater challenge than that created by 3-circle column (Level 2) and 3-circle row (Level 3) configurations.

Level 5:

Central fixation cross disappears, and 5-circle configuration appears. "Cue" stimulus circle (filled or open) marked with cross may be in any one of the 5 positions.

Subject must rapidly identify the "cue" stimulus circle marked with cross to visual track its motion relative to that of the other flanking/distracting circles.

Level 6:

Central fixation cross disappears, and 5-circle configuration appears in any of 4 screen quadrants (Upper-Left, Lower-Left, Upper-Right, or Lower-Right. "Cue" stimulus circle (filled or open) marked with cross may be in any one of the 5 positions.

Subject must rapidly identify "cue" stimulus circle marked with cross to visual track its motion relative to that of the other flanking/distracting circles.

EXAMPLE 3

This example relates the results of perceptual-motor training of college football players, which was improved in accordance with certain embodiments. Interrelationships among performance metrics linked to brain processing efficiency were assessed in this example for a cohort of college football players. A retrospective association between suboptimal conflict resolution and prior core or lower extremity injury during football participation (i.e., previous 12 months) was used to assess the potential for perceptual-motor performance improvement in players believed to possess elevated injury risk.

In this example, a smartphone app was used to administer the Ericksen flanker test to a cohort of 87 players (20.7 +/- 1.7 years; 185.2 +/- 10.1 cm; 102.5 +/- 19.5 kg) during the week prior to initiation of pre-season practice sessions. Rapid manual tilting of the device registered responses to the center arrow directions of 5-arrow congruent and incongruent stimuli. Speed-accuracy trade-off was quantified by Rate Correct per Second (RCS) of response time and Flanker Conflict Effect (FCE) represented difference in average response times for 10 incongruent and 10 congruent displays. Reaction Time Variability (RTV) was defined as the intra-individual standard deviation of 20 response times. Data retained for analysis corresponded to those with the higher RCS value from 2 consecutive trials, which demonstrated very high consistency (2-Way Random ICC=.770). A subset of 25 players who exhibited FCE greater than or equal to 66 ms, which was associated with having sustained a core or lower extremity sprain or strain during the preceding 12 months (OR=6.23; 95% CI: 2.12, 18.35), Participated in training sessions that involved 2 sets of 20 lower extremity lunging motions corresponding to stimulus-response instructions for open versus solid cue stimulus circle movements from the center to outer margins of a computer monitor. Moving visual-cognitive stimuli of progressively increasing difficulty were administered 1-3 times per week during the first 4 weeks of the regular season. All core and lower extremity sprains and strains that disrupted participation in a practice session or game were documented. Players available for testing at the end of the 11-game season permitted a pre- to post-season comparison of performance values for 15 players who completed the 4-week training program to those of 40 players who did no perceptual-motor training.

Correlations between RTV and FCE ($r=0.436$; $p<0.001$) and between RTV and RCS ($r=-0.298$; $p=0.005$) were evident in the full cohort of 87 players. Multiple correlation of FCE and RCS with RTV was substantial ($R=0.516$; $p<0.001$), with negligible collinearity. A median of 8 training sessions were completed by the 15 players in the training group who were available for post-season follow-up testing. Paired-samples t-test results demonstrated significant increase in RCS (1.84 +/- 0.19 to 1.91 +/- 0.16; $p=0.007$), but no significant change in FCE or RTV. Further analysis demonstrated a change in proportion of correct responses (0.93 +/- 0.08 to 0.96 +/- 0.06; $p=0.055$), but no change in average response time (505 +/- 41 to 505 +/- 42 ms; $p=0.972$). An independent t-test demonstrated a significant difference between training and no training groups (15 and 40 players, respectively) for pre-participation to post-season RCS change (0.15 +/- 0.09 versus 0.03 +/- 0.24; $p=0.008$). An across-season RCS decrease of 0.16 or greater was retrospectively associated with significantly greater odds for a core or lower extremity sprain or strain having been sustained (OR=7.04; 95%CI: 1.41, 35.04). The fact that there was a comparable number of starters in each group, 47% (7/15) and 45% (18/40), suggests that differential exposure to game conditions was not a confounding factor.

Thus, it was concluded that suboptimal perceptual-motor test metrics may represent inefficient brain processing that can be improved through training. Accumulating evidence from recent studies suggests that repetitive head impacts sustained across a football season can adversely affect brain processing speed and accuracy. This post-season retrospective analysis of injury occurrences suggests that perceptual-motor training performed during the football season may have value as an injury prevention strategy that offsets the deleterious effects of repetitive head impacts that accumulate over the course of a season.

EXAMPLE 4

In this example, a total of 75 college students (20.7 +/- 2.1 years) from 3 different organizational cohorts voluntarily participated in a virtual reality (VR) test and provided survey responses relating to current well-being. The participants included 39 military cadets (29 male, 10 female), 16 college football players, and 20 college wrestlers.

The VR test involved 40 lunging/reaching movements in left or right directions in response to the directional motion of horizontally moving white circles that were visible for 250 ms against a black background on the headset screen (Pico Neo 3 Pro Eye, ByteDance, Ltd., Bejing, China). Prior to test initiation, each participant assumed a “T-pose” with VR controllers in each hand (i.e., standing upright with horizontally outstretched arms) to acquire a measurement that was used to calibrate the lunging/reaching distance required to make

contact with a VR response target (i.e., a green sphere) located beyond the peripheral margin of the visual field when looking forward. An example screenshot of such a VR test is shown in Fig. 6, depicting green target spheres prior to T-pose calibration (response targets located beyond field of view margins after calibration). Stimulus-response instructions were to lunge/reach to hit the green target sphere located in the same direction as the horizontal motion of "solid" white circles (i.e., congruent stimulus-response motion) and to lunge/reach to hit the green target sphere located in the opposite direction to the horizontal motion of "open" circles with a white border (i.e., incongruent stimulus-response motion). Participants were instructed to assume a semi-crouched ready position, with feet positioned at shoulder width and hand controllers against the chest. A central fixation cross appeared on the VR headset screen prior to the initiation of each trial to ensure that the eyes were centrally positioned before a moving circle stimulus appeared. On a given trial, a solid or open circle either initially appeared in a central position and disappeared at the left or right peripheral margin of the viewing screen or it initially emerged from either the left or right peripheral margin and disappeared at the center.

Thus, 4 types of moving stimuli (i.e., congruent versus incongruent and central versus peripheral initial appearance) were randomly presented in rapid succession for total of 40 trials. The speed and direction of a given response was derived from an eye tracking camera and an accelerometer within the VR headset, as well as the sensors within the hand controllers, which collectively quantified eye, neck, and arm movements, and lower extremity lunge-step impact on the ground. Both an auditory tone and controller vibration were provided as feedback confirmation that a response target had been contacted. See Figs. 5A-5D for examples of the 8 combinations of stimulus type (congruent or incongruent), initial appearance position (center or periphery), and stimulus movement direction (left or right).

Performance metrics derived from VR hand controller (i.e., arm reach) movement responses included Rate Correct per Second (RCS: number of correct directional responses divided by the sum of response times), Motion Conflict Effect (MCE: median of 20 incongruent response times minus median of 20 congruent response times), and Reaction Time Variability (RTV: standard deviation of 40 response times). Additionally, VR Dispersion represented the intra-individual standard deviation of standardized (i.e., T-score) values for multiple metrics derived from eye, neck, arm, and lower extremity response times for the 4 different types of visual stimuli. An advantage of T-score standardization is representation of standard deviations above and below a standardized mean value of 50 in

units of 10. Because prior research has associated "dispersion" of standardized performance values for tasks representing different domains of cognitive function with various neurodegenerative disorders, the prospectively selected performance metric of primary interest was VR Dispersion.

The Sport Fitness and Wellness Index (SFWI) provides a global estimate of well-being that is derived from a combination of responses to the Sport Fitness Index and the Overall Wellness Index surveys, both of which have been validated as indicators of suboptimal status. A 0-100 SFWI score was generated from responses to 20 items pertaining to persisting effects of prior musculoskeletal injuries, physical problems, sleep disruption, cognitive limitations, and mood disorders (i.e., high score corresponding to overall status self-rated as optimal).

Receiver operating characteristic analysis area under curve (AUC) was used to assess the strength of univariable association of potential predictive variables with self-reported history of concussion. Youden's Index was used to identify the optimal cut point for maximum discrimination, which permitted cross-tabulation analysis for determination of sensitivity, specificity, and an odds ratio (OR) and its 95% confidence interval (CI). Logistic regression analysis was used to assess various combinations of continuous predictive variables for maximum discrimination. To avoid overfitting, the logistic regression modeling was limited to the strongest 2-factor combination of predictive variables. To potentially simplify interpretation of the logistic regression result, binary modeling of the strongest 2-factor combination of variables was also performed.

A history of concussion (HxC) was self-reported by 20 participants (29.2 +/- 27.1 months prior, range: 3-96) and denied by 55 participants (NoC). Complete VR test data were acquired for neck, arm, and lower extremity responses, but 11.3% (34/300) of the eye tracking test results for the 4 combinations of visual stimulus types were not captured. Rather than inserting cohort median values for the missing data, the analysis was limited to potential predictive variables with complete data for the 75 participants. Thus, VR Dispersion was based on the median response times of 3 movement types (i.e., neck, arm, and lower extremity) for each of 4 visual stimulus types (i.e., 12 T-scores).

Each of the VR metrics and SFI score exhibited a univariable association with HxC (RCS AUC=.556; CE AUC=.615; RTV AUC=.615; VR Dispersion AUC=.593; SFWI AUC=.813). Backward stepwise logistic regression modeling included each VR metric, SFWI, and interaction between each VR metric and SFWI. The best 2-factor model included of VR Dispersion (beta=2.74, $p<.001$) and the interaction of VR Dispersion with SFWI

(beta=–0.03, p<.001), which provided 81% HxC classification accuracy (Model χ^2 =26.03, p<.001; Hosmer & Lemeshow χ^2 =1.86, p=.967; Nagelkerke R^2=.427; Area Under Curve=.841, 95% CI: .734, .948). Binary modeling that included VR Dispersion ≥3.2 (range: 1.5-21.8) and SFWI ≤86 (range: 44-100) demonstrated 75% sensitivity and 86% specificity with both positive (Odds Ratio=17.6, 95% CI: 5.0, 62.1), with an evident interaction effect (Fig. 7). Median and inter-quartile range (IQR) values for VR Dispersion were 3.5 (2.8, 5.0) for NoC and 4.4 (3.4, 5.6) for HxC. Corresponding values for SFWI score were 92 (82, 97) for NoC and 72 (60, 83) for HxC. Among the 20 cases of self-reported HxC, the most commonly reported factors adversely affecting well-being related to physical discomfort, sleep disruption, and mood disorders (see table below).

Table 1

Complaint	Number
Headaches	9
Trouble Falling Asleep	8
Muscle Aches	7
Joint Aches	6
Anxiety	6
Nervousness	5
Sleeping Less	5
Fatigue/Lethargy	5

EXAMPLE 5

This example illustrates data visualizations that illustrate differences between 2 individuals (college football players), in accordance with certain embodiments of the invention. In particular, this example illustrates the simultaneous engagement of visual-cognitive processes and multi-segmental muscle responses.

Figs. 4A-4B illustrate synchronization of eye, neck, arm, and lower extremity responses, and suboptimal synchronization associated with prolonged and less accurate responses to the test stimuli. Each of the metrics listed in the tables adjacent to the movement tracking illustrations are better for case 1 than case 2. Both cases in this example have a history of sport-related concussion, but case 2 sustained his injury more recently.

Dispersion refers to variability among 16 standardized measures (individual's values in relation to a group mean value) derived from the test (4 body parts (eye, neck, arm, and

lower extremity) and 2 stimulus types (incongruent and congruent) at 2 locations of initial stimulus presentation (central and peripheral)). "Latency+ refers to the time between stimulus appearance and initiation of movement, whereas "Response" refers to the time between stimulus appearance and movement beyond a specified threshold. The "Dispersion" values provide a numerical representation of the illustrated degree of synchronization among the 4 body parts and the 4 possible combinations of trial type.

While several embodiments of the present disclosure have been described and illustrated herein, those of ordinary skill in the art will readily envision a variety of other means and/or structures for performing the functions and/or obtaining the results and/or one or more of the advantages described herein, and each of such variations and/or modifications is deemed to be within the scope of the present disclosure. More generally, those skilled in the art will readily appreciate that all parameters, dimensions, materials, and configurations described herein are meant to be exemplary and that the actual parameters, dimensions, materials, and/or configurations will depend upon the specific application or applications for which the teachings of the present disclosure is/are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments of the disclosure described herein. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, the disclosure may be practiced otherwise than as specifically described and claimed. The present disclosure is directed to each individual feature, system, article, material, kit, and/or method described herein. In addition, any combination of two or more such features, systems, articles, materials, kits, and/or methods, if such features, systems, articles, materials, kits, and/or methods are not mutually inconsistent, is included within the scope of the present disclosure.

In cases where the present specification and a document incorporated by reference include conflicting and/or inconsistent disclosure, the present specification shall control. If two or more documents incorporated by reference include conflicting and/or inconsistent disclosure with respect to each other, then the document having the later effective date shall control.

All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

The indefinite articles "a" and "an," as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean "at least one."

The phrase "and/or," as used herein in the specification and in the claims, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, a reference to "A and/or B", when used in conjunction with open-ended language such as "comprising" can refer, in one embodiment, to A only (optionally including elements other than B); in another embodiment, to B only (optionally including elements other than A); in yet another embodiment, to both A and B (optionally including other elements); etc.

As used herein in the specification and in the claims, "or" should be understood to have the same meaning as "and/or" as defined above. For example, when separating items in a list, "or" or "and/or" shall be interpreted as being inclusive, i.e., the inclusion of at least one, but also including more than one, of a number or list of elements, and, optionally, additional unlisted items. Only terms clearly indicated to the contrary, such as "only one of" or "exactly one of," or, when used in the claims, "consisting of," will refer to the inclusion of exactly one element of a number or list of elements. In general, the term "or" as used herein shall only be interpreted as indicating exclusive alternatives (i.e. "one or the other but not both") when preceded by terms of exclusivity, such as "either," "one of," "only one of," or "exactly one of."

As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another

embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements); etc.

When the word "about" is used herein in reference to a number, it should be understood that still another embodiment of the disclosure includes that number not modified by the presence of the word "about."

It should also be understood that, unless clearly indicated to the contrary, in any methods claimed herein that include more than one step or act, the order of the steps or acts of the method is not necessarily limited to the order in which the steps or acts of the method are recited.

In the claims, as well as in the specification above, all transitional phrases such as "comprising," "including," "carrying," "having," "containing," "involving," "holding," "composed of," and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of" and "consisting essentially of" shall be closed or semi-closed transitional phrases, respectively, as set forth in the United States Patent Office Manual of Patent Examining Procedures, Section 2111.03.

What is claimed is:

CLAIMS

1. A method, comprising:

displaying, to a subject, a discrimination test and a plurality of response targets that appear to be at least 1 meter away from the subject;

determining a response target of the plurality of response targets that the subject appears to touch in response to the discrimination test; and

determining a reaction time and/or an accuracy of the subject in response to the discrimination test.

2. The method of any one of claims 1-, comprising displaying, to the subject, a plurality of discrimination tasks, including one or more choices involving visual objects displaying congruent characteristics and one or more choices involving visual objects displaying incongruent characteristics.

3. The method of claim 2, wherein the one or more choices involving visual objects displaying congruent characteristics and the one or more choices involving visual objects displaying incongruent characteristics are displayed in random order.

4. The method of any one of claims 2 or 3, wherein a choice involving visual objects displaying congruent characteristics comprises displaying a first visual object and a choice involving visual objects displaying incongruent characteristics comprises displaying a second object visually distinct from the first visual object.

5. The method of any one of claims 2-4, wherein at least one of the discrimination tasks comprises displaying one or more moving visual objects.

6. The method of claim 5, wherein in the discrimination task, the subject's accuracy is determined based on a response to a response target in a location congruent with the direction and appearance of a moving visual object designated as congruent, and the subject's accuracy is determined based on a response to a response target in a location

incongruent with the direction and appearance of a moving visual object designated as incongruent.

7. The method of any one of claims 2-6, wherein the plurality of response targets remain in a fixed position.

8. The method of any one of claims 2-7, wherein the plurality of response targets remain visually identical between discrimination tasks.

9. The method of any one of claims 2-8, wherein determining the accuracy comprises determining the subject's spatial accuracy in touching the plurality of response targets.

10. The method of any one of claims 1-9, wherein determining a response target that the subject appears to touch comprises determining a direction of displacement of the subject.

11. The method of any one of claims 1-10, wherein determining a response target that the subject appears to touch comprises determining a movement of the subject.

12. The method of any one of claims 1-11, wherein determining a response target that the subject appears to touch comprises determining one or more steps taken by the subject.

13. The method of any one of claims 1-12, wherein determining a response target that the subject appears to touch comprises determining leftward motions taken by the subject and rightward motions taken by the subject.

14. The method of any one of claims 1-13, wherein determining the reaction time comprises determining a reaction time between the time the discrimination task is displayed, and a response of the subject's eyes to the discrimination task.

15. The method of claim 14, comprising determining a subject's eye position using an eye tracking sensor.

16. The method of any one of claims 1-15, wherein determining the reaction time comprises determining a reaction time between a response of the subject's eyes to the discrimination task, and the time the subject begins moving towards one of the response targets.

17. The method of any one of claims 1-16, wherein determining the reaction time comprises determining a reaction time between the time the subject begins moving towards one of the response targets, and the time the subject reaches the response target.

18. The method of any one of claims 1-17, comprising determining the response target that the subject appears to touch using a motion sensor.

19. The method of claim 18, comprising determining the response target that the subject appears to touch using two motion sensors attached to a subject's hands, arms, trunk, or lower extremities.

20. The method of any one of claims 1-19, comprising displaying the discrimination test to the subject on a display.

21. The method of claim 20, wherein the display is part of a VR device.

22. The method of claim 20, wherein the display is part of a smartphone.

23. The method of any one of claims 1-22, further comprising displaying, to the subject, a focal point prior to displaying the discrimination test.

24. The method of any one of claims 1-23, wherein the subject has a neurological condition.

25. The method of any one of claims 1-24, wherein the subject has a musculoskeletal condition.

26. The method of any one of claims 1-25, comprising increasing the difficulty of the plurality of discrimination tasks in response to the subject's reaction time and/or an accuracy.

27. The method of claim 26, wherein the difficulty is increased adaptively.

28. A method, comprising:

applying the method of any one of claims 1-27 multiple times to the subject.

29. The method of claim 28, wherein the applications are separated by at least 12 hours.

30. A method, comprising:

(a) displaying, to a subject, a visual stimulus comprising either a first moving object or a second moving object, wherein the first moving object and the second moving object are visually distinct;

(b) displaying, to the subject, a plurality of response targets that appear to be positioned to require the subject to take at least one step to reach;

(c) determining which response target of the plurality of response targets the subject appears to touch in response to the visual stimulus comprising either the first moving object or the second moving object;

(d) repeating (a)-(c) at least once; and

(e) determining the subject's accuracy in touching the corresponding response targets in response to the plurality of displayed visual stimuli.

31. The method of claim 30, wherein the first moving visual object indicates a response target in a direction congruent to a direction of motion of the first moving visual object, and the second moving visual object indicates a response target in a direction incongruent to a direction of motion of the second moving visual object.

32. A method, comprising:

displaying, to a subject, a visual stimulus comprising a plurality of moving objects;

displaying, to the subject, a plurality of response targets;

determining a response target of the plurality of response targets that the subject appears to touch in response to the visual stimulus; and

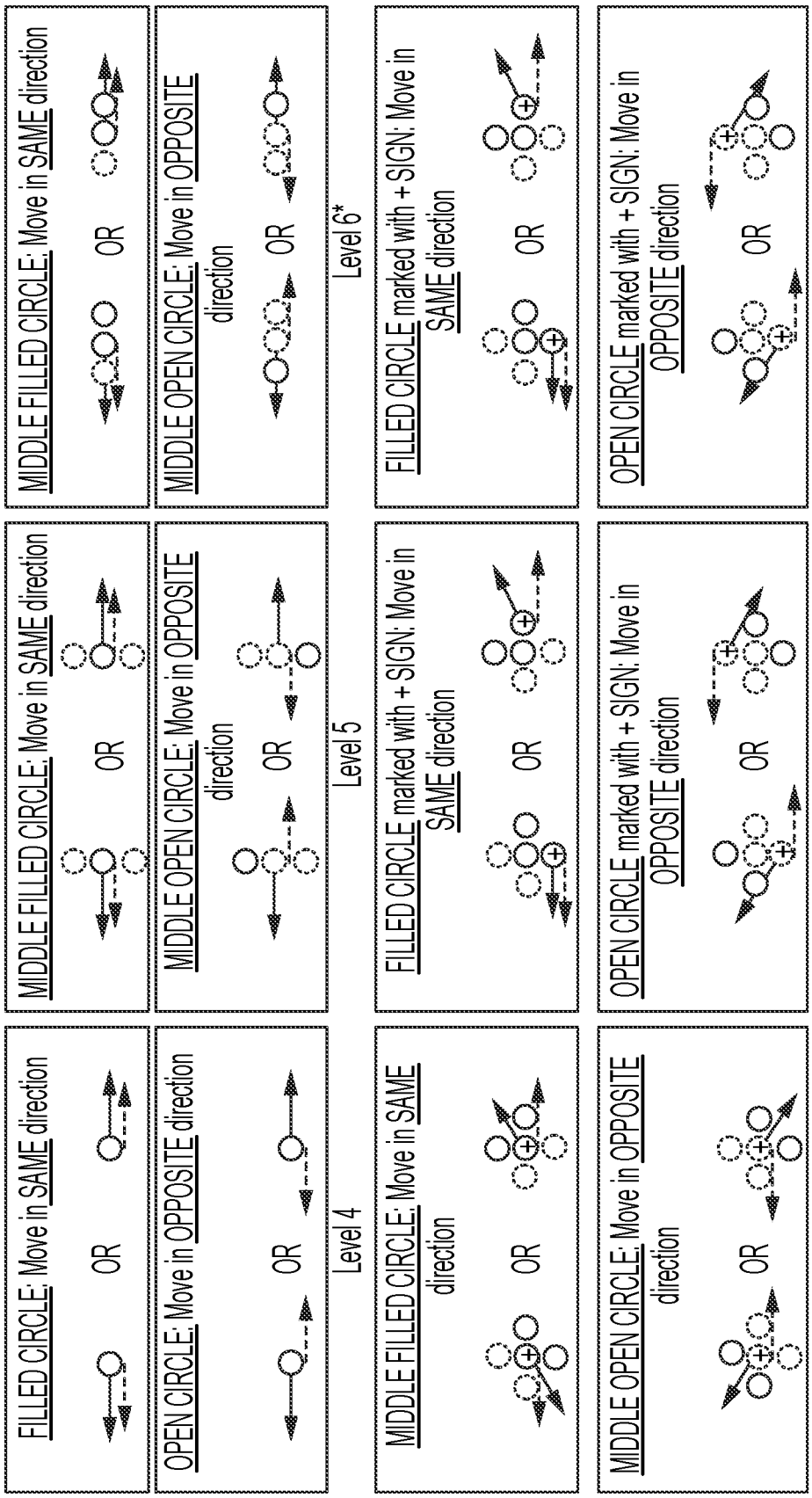
determining a plurality of reaction times, including at least two of:

(a) a reaction time between the time the visual stimulus is displayed, and a response of the subject's eyes to the visual stimulus;

(b) a reaction time between the response of the subject's eyes to the visual stimulus, and the time the subject begins moving towards one of the response targets; and

(c) a reaction time between the time the subject begins moving towards one of the response targets, and the time the subject reaches the response target.

33. The method of claim 32, wherein the plurality of response targets are positioned to require the subject to take at least one step to reach.


Level 1
FILLED CIRCLE: Move in SAME direction
OR
OPEN CIRCLE: Move in OPPOSITE direction
OR
Level 2
MIDDLE FILLED CIRCLE: Move in SAME direction
OR
MIDDLE OPEN CIRCLE: Move in OPPOSITE direction
OR
Level 3
MIDDLE FILLED CIRCLE: Move in SAME direction
OR
MIDDLE OPEN CIRCLE: Move in OPPOSITE direction
OR
Level 4
MIDDLE FILLED CIRCLE: Move in SAME direction
OR
MIDDLE OPEN CIRCLE: Move in OPPOSITE direction
OR
Level 5
FILLED CIRCLE marked with + SIGN: Move in SAME direction
OR
OPEN CIRCLE marked with + SIGN: Move in OPPOSITE direction
OR
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OR
OPEN CIRCLE marked with + SIGN: Move in OPPOSITE direction
OR

FIG. 1

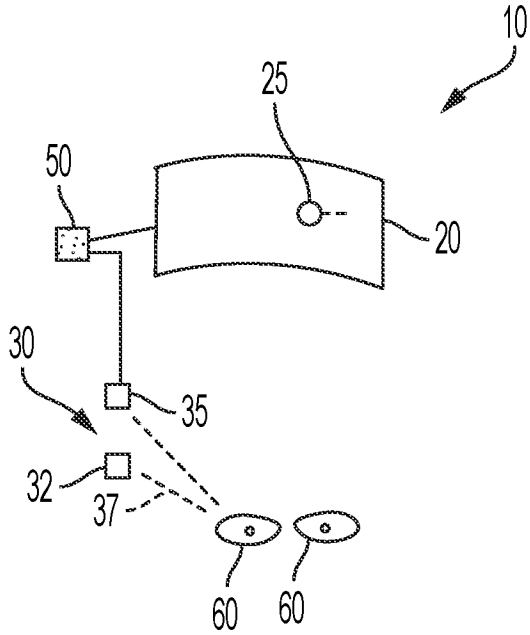


FIG. 2

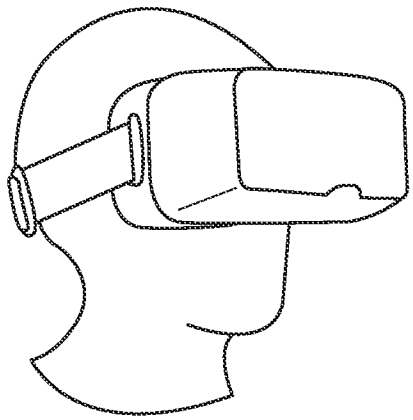
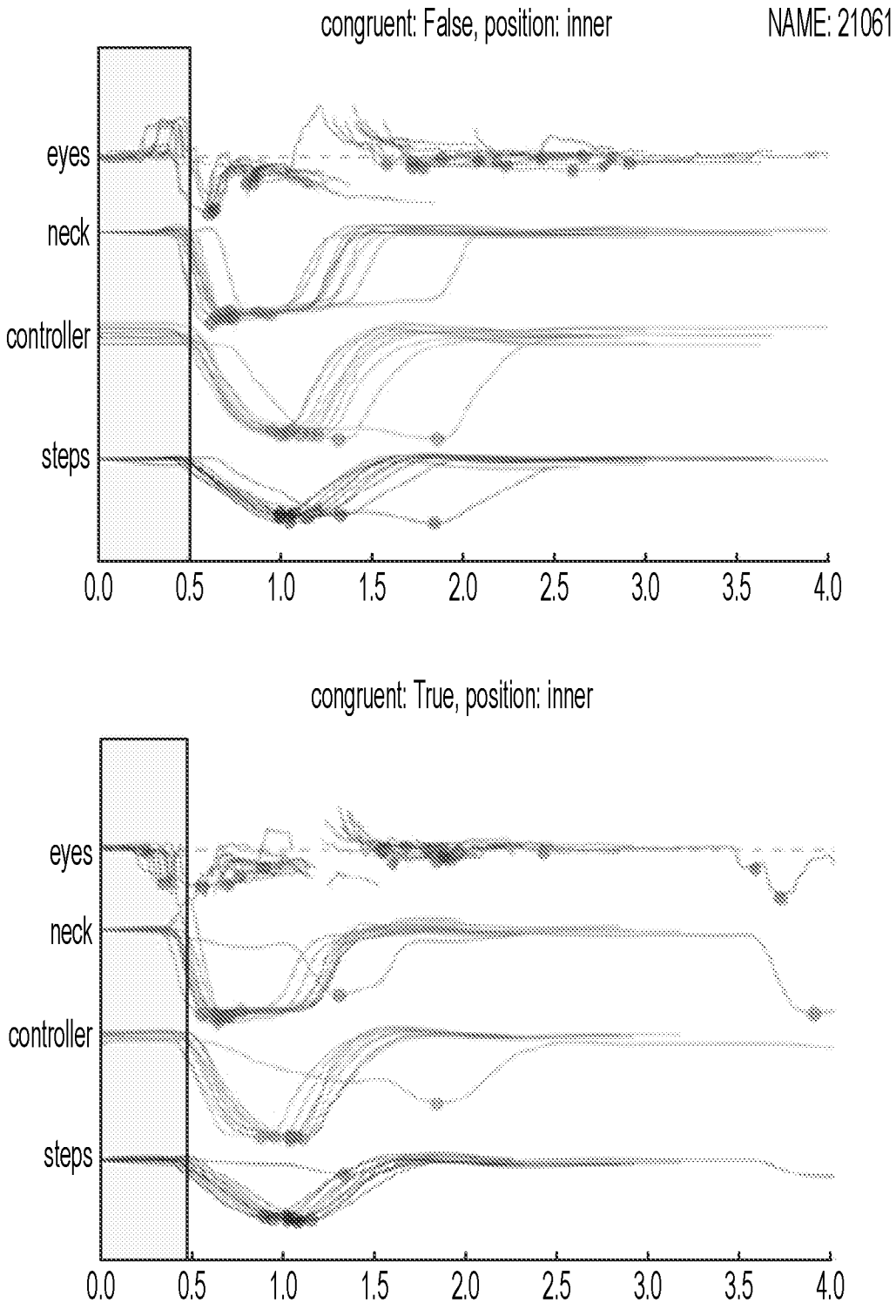


FIG. 3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NAME: 21061
eyes
neck
controller
steps
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
congruent: True, position: inner
eyes
neck
controller
steps
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0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

FIG. 4A

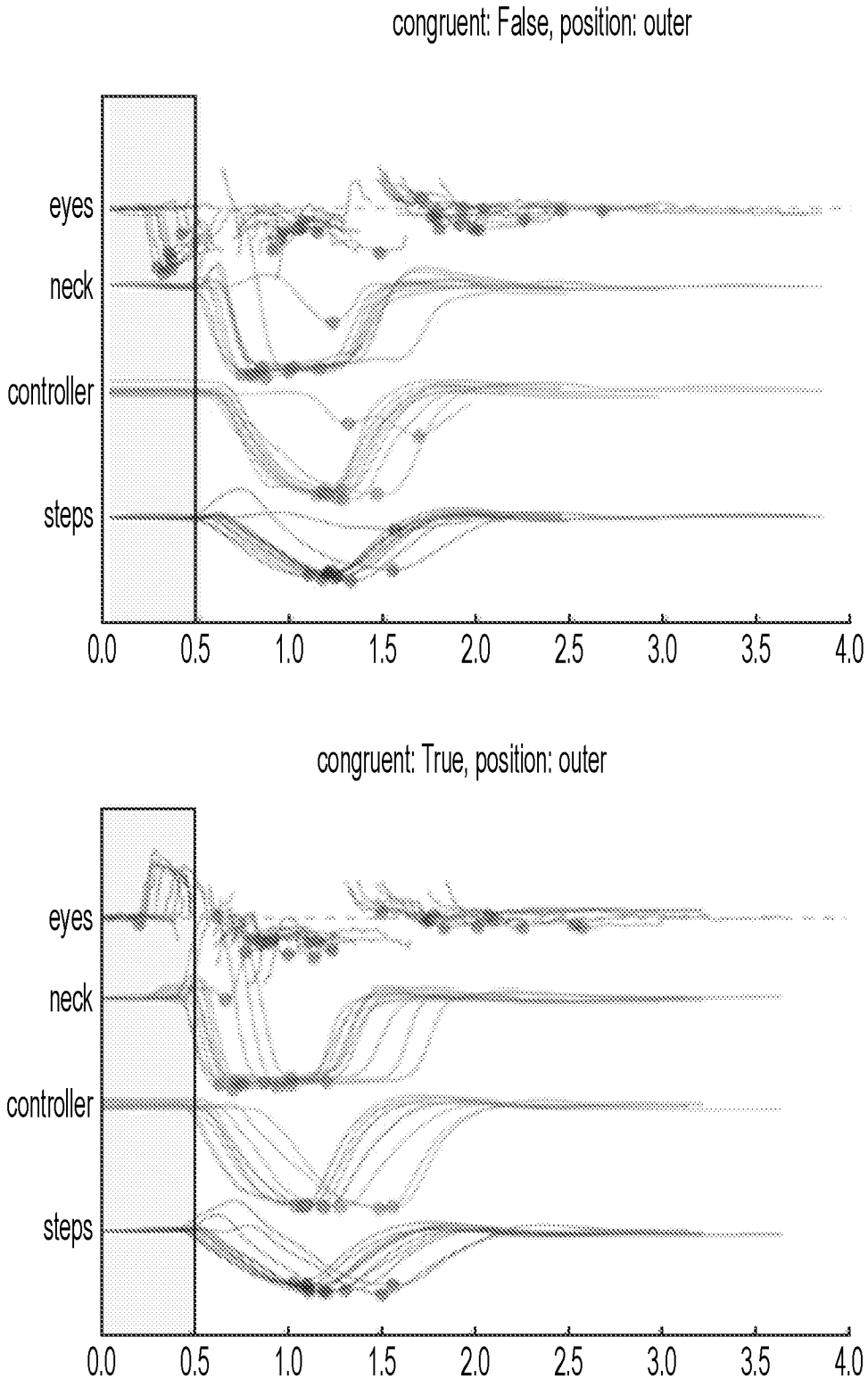
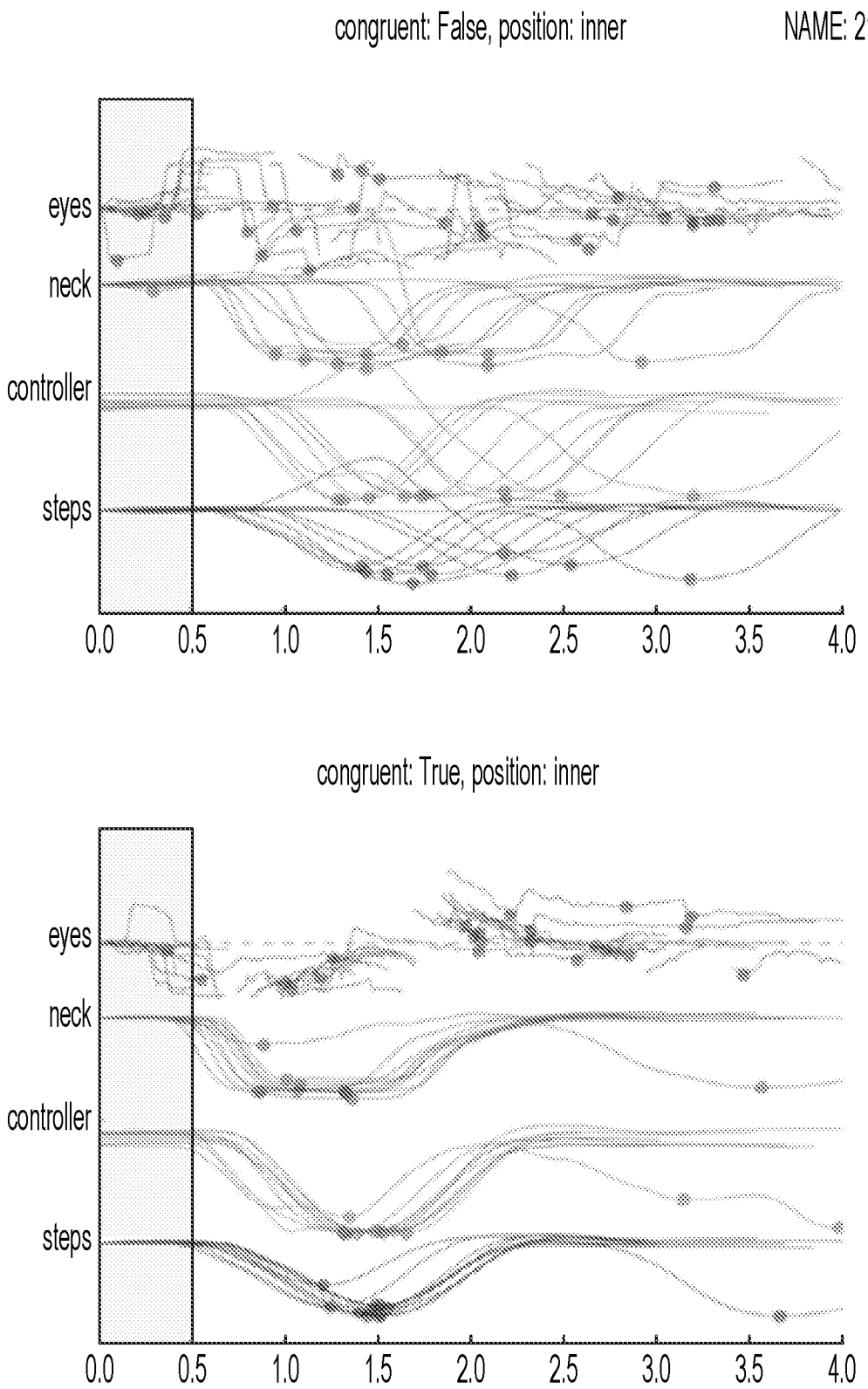


FIG. 4A
continued

Football Position	DB
Months since SRC	96
Sport Fitness & Wellness Index	95
Response Dispersion (16 Standard Scores)	5.58
Latency Dispersion (16 Standard Scores)	5.59
Correct Response % (40 Trials)	95.0%
Rate Correct per Second	1.62
Average Response Time	1.002 s
Conflict Effect (Incongruent - Congruent)	.038 s
Left - Right Target Response Time Difference	.027 s

FIG. 4A
continued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NAME: 21022
eyes
neck
controller
steps
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
congruent: True, position: inner
eyes
neck
controller
steps
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

FIG. 4B

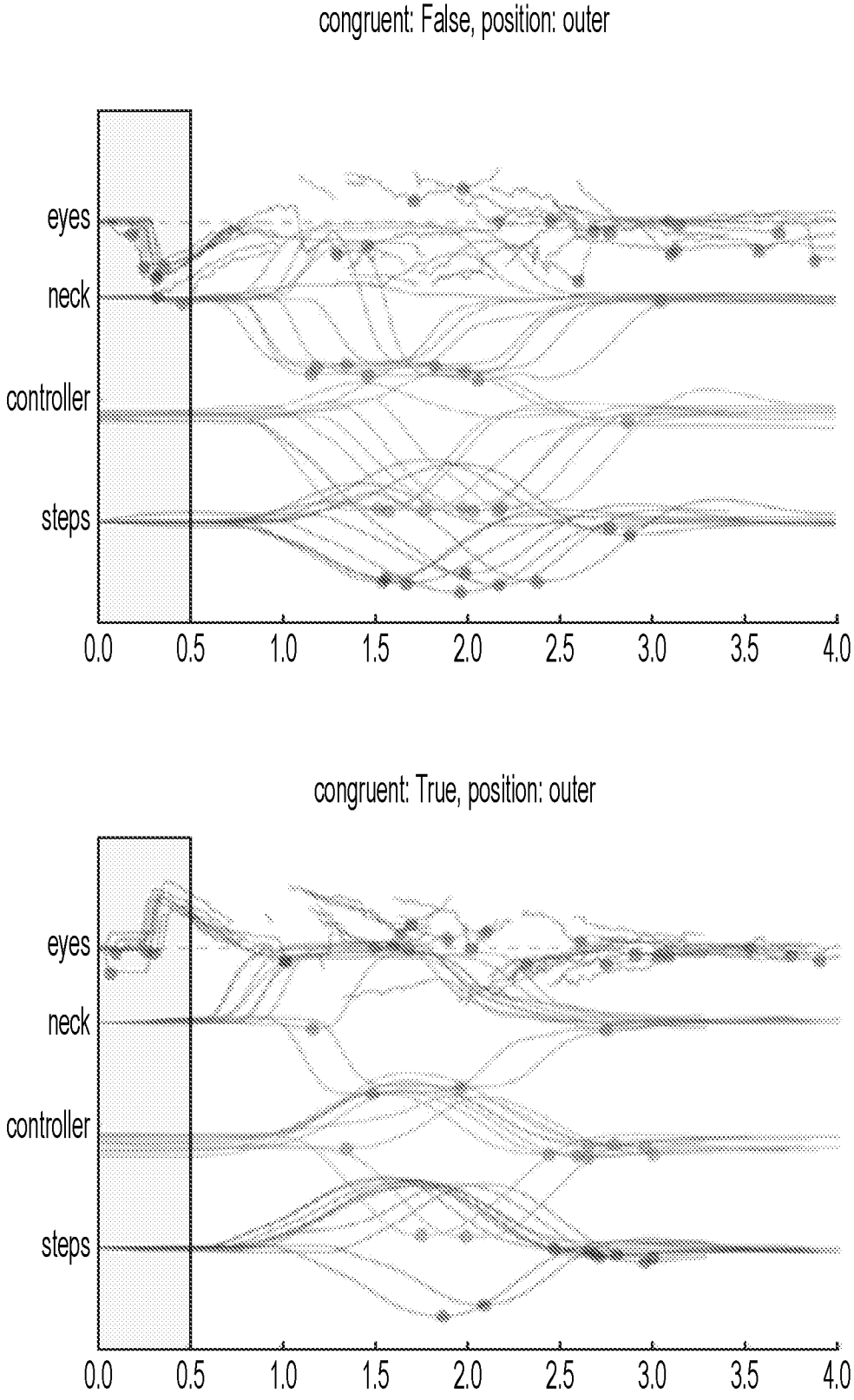

FIG. 4B
continued

Football Position	DB
Months since SRC	32
Sport Fitness & Wellness Index	79
Response Dispersion (16 Standard Scores)	10.13
Latency Dispersion (16 Standard Scores)	11.22
Correct Response % (40 Trials)	72.5
Rate Correct per Second	0.49
Average Response Time	1.323 s
Conflict Effect (Incongruent - Congruent)	.209 s
Left - Right Target Response Time Difference	.083 s

FIG. 4B
continued

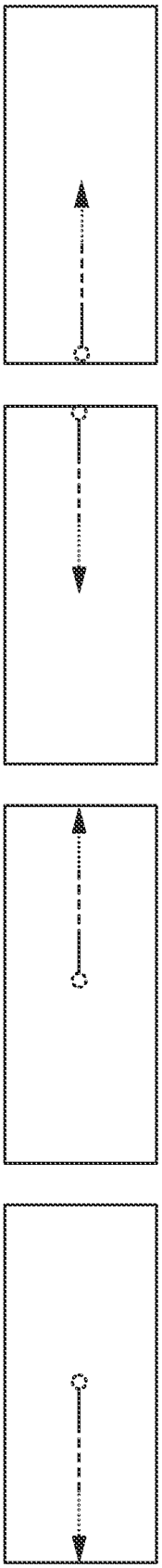

FIG. 5A

FIG. 5B

FIG. 5C

FIG. 5D

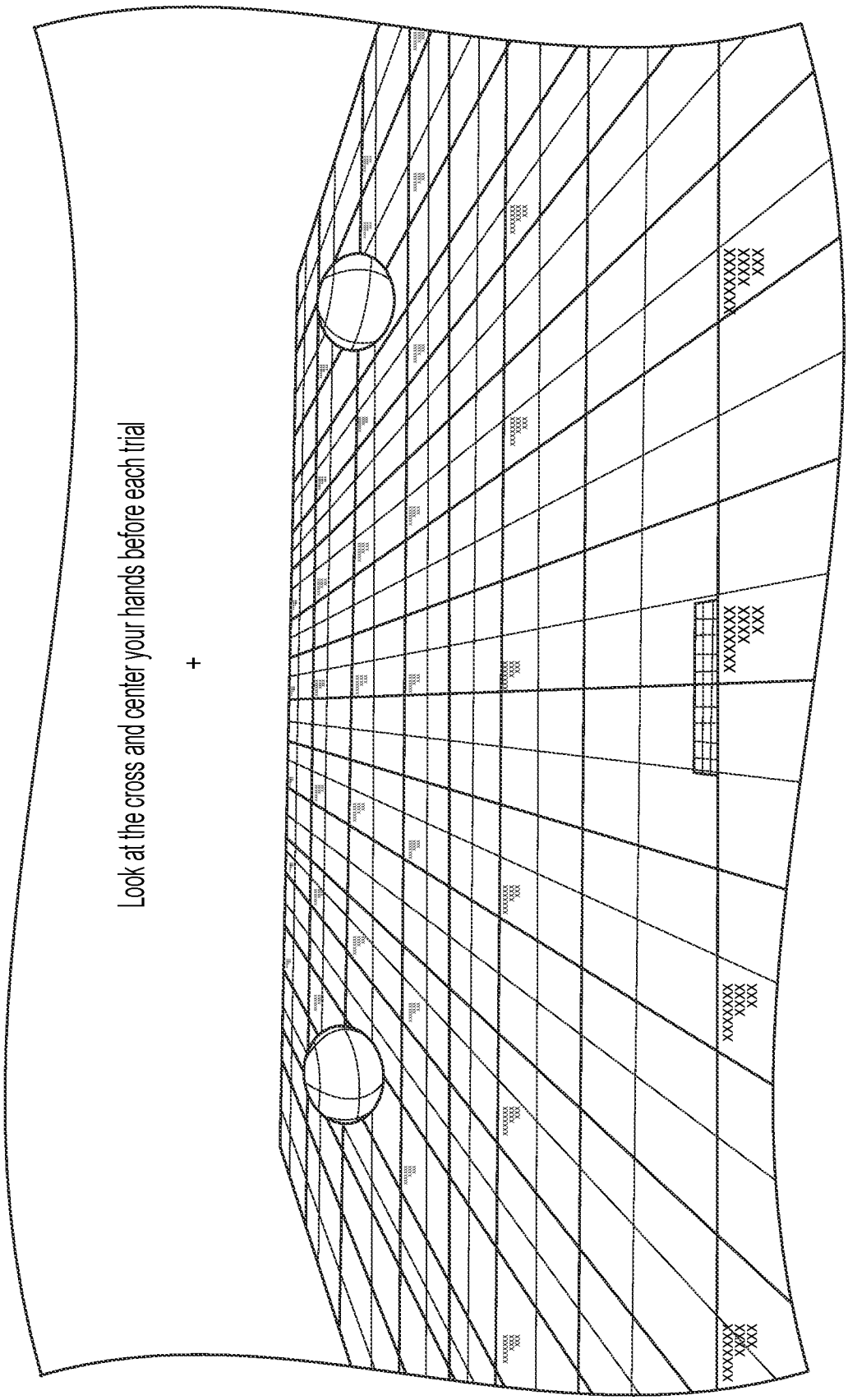

FIG. 6

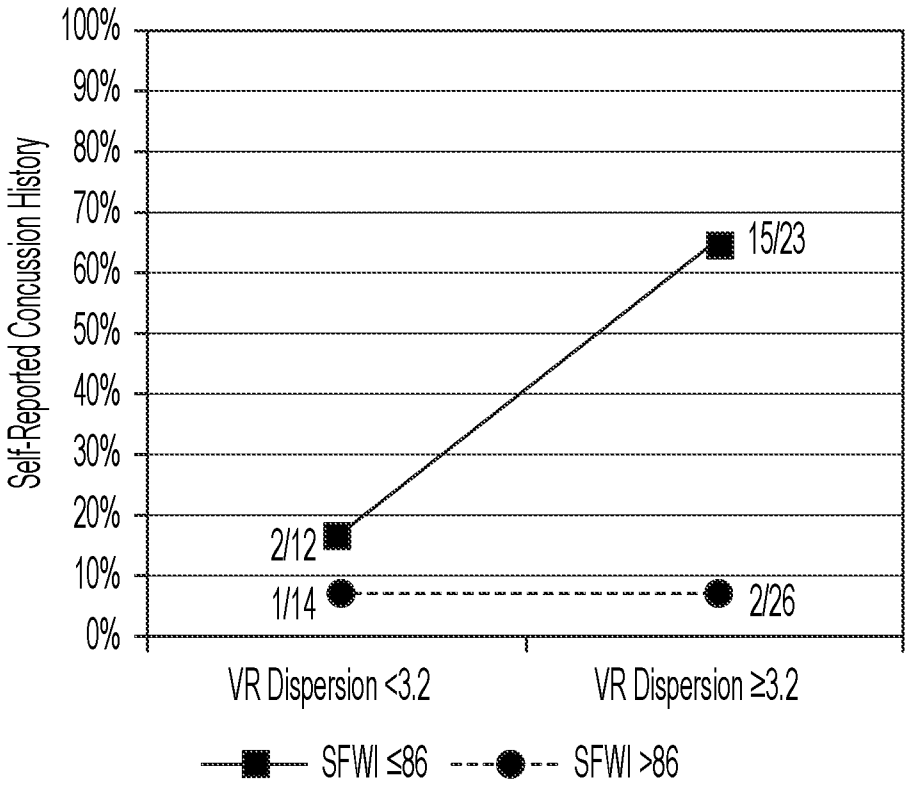
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Self-Reported Concussion History
15/23
2/12
1/14
2/26
VR Dispersion <3.2
VR Dispersion ≥3.2
SFWI ≤86
SFWI >86

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/027595

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - INV. - A61B 5/16; G16H 20/70 (2023.01)
ADD. - G16H 50/30 (2023.01)

CPC - INV. - A61B 5/162; G16H 20/70 (2023.08)
ADD. - G16H 50/30 (2023.08)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2019/0026681 A1 (PYMETRICS, INC.) 24 January 2019 (24.01.2019) entire document	1-4
Y	US 2012/0075586 A1 (KIRSCHEN et al.) 29 March 2012 (29.03.2012) entire document	1-4
A	US 2018/0090024 A1 (TALI HEALTH PTY LTD et al.) 29 March 2018 (29.03.2018) entire document	1-4
A	WO 2017/141166 A1 (HICHEUR) 24 August 2017 (24.08.2017) entire document	1-4
A	US 2018/0308383 A1 (MILLISECOND SOFTWARE LLC) 25 October 2018 (25.10.2018) entire document	1-4
A	WO 2017/108441 A1 (UNIVERSITEIT MAASTRICHT et al.) 29 June 2017 (29.06.2017) entire document	1-4

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 November 2023	DEC 13 2023
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Taina Matos Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/027595

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 5-29
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet(s).

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-4

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2023/027595

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-4, is drawn to a method, comprising: displaying, to a subject, a discrimination test and a plurality of response targets that appear to be at least 1 meter away from the subject.

Group II, claims 30 and 31, is drawn to a method, comprising: displaying, to a subject, a visual stimulus comprising either a first moving object or a second moving object, wherein the first moving object and the second moving object are visually distinct.

Group III, claims 32 and 33, is drawn to a method, comprising: determining a plurality of reaction times, including at least two of: a reaction time between the time the visual stimulus is displayed, and a response of the subject's eyes to the visual stimulus.

The inventions listed as Groups I, II and III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: displaying, to a subject, a discrimination test and a plurality of response targets that appear to be at least 1 meter away from the subject; determining a response target of the plurality of response targets that the subject appears to touch in response to the discrimination test; and determining a reaction time and/or an accuracy of the subject in response to the discrimination test as claimed therein is not present in the invention of Groups II and III. The special technical feature of the Group II invention: displaying, to the subject, a plurality of response targets that appear to be positioned to require the subject to take at least one step to reach; determining which response target of the plurality of response targets the subject appears to touch in response to the visual stimulus comprising either the first moving object or the second moving object; repeating (a)-(c) at least once; and determining the subject's accuracy in touching the corresponding response targets in response to the plurality of displayed visual stimuli as claimed therein is not present in the invention of Groups I or III. The special technical feature of the Group III invention: determining a plurality of reaction times, including at least two of: a reaction time between the time the visual stimulus is displayed, and a response of the subject's eyes to the visual stimulus; a reaction time between the response of the subject's eyes to the visual stimulus, and the time the subject begins moving towards one of the response targets; and a reaction time between the time the subject begins moving towards one of the response targets, and the time the subject reaches the response target as claimed therein is not present in the invention of Groups I or II.

Groups I, II and III lack unity of invention because even though the inventions of these groups require the technical feature of a method, comprising: displaying, to a subject, a visual stimulus comprising a plurality of moving objects; displaying, to the subject, a plurality of response targets; determining a response target of the plurality of response targets that the subject appears to touch in response to the visual stimulus, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2018/0090024 to TALI Health Pty Ltd et al. teaches a method, comprising: displaying, to a subject, a visual stimulus comprising a plurality of moving objects; displaying, to the subject, a plurality of response targets; determining a response target of the plurality of response targets that the subject appears to touch in response to the visual stimulus (Paras. [0110], [0116-0120]. Also See Table 1).

Since none of the special technical features of the Group I, II or III inventions are found in more than one of the inventions, unity of invention is lacking.