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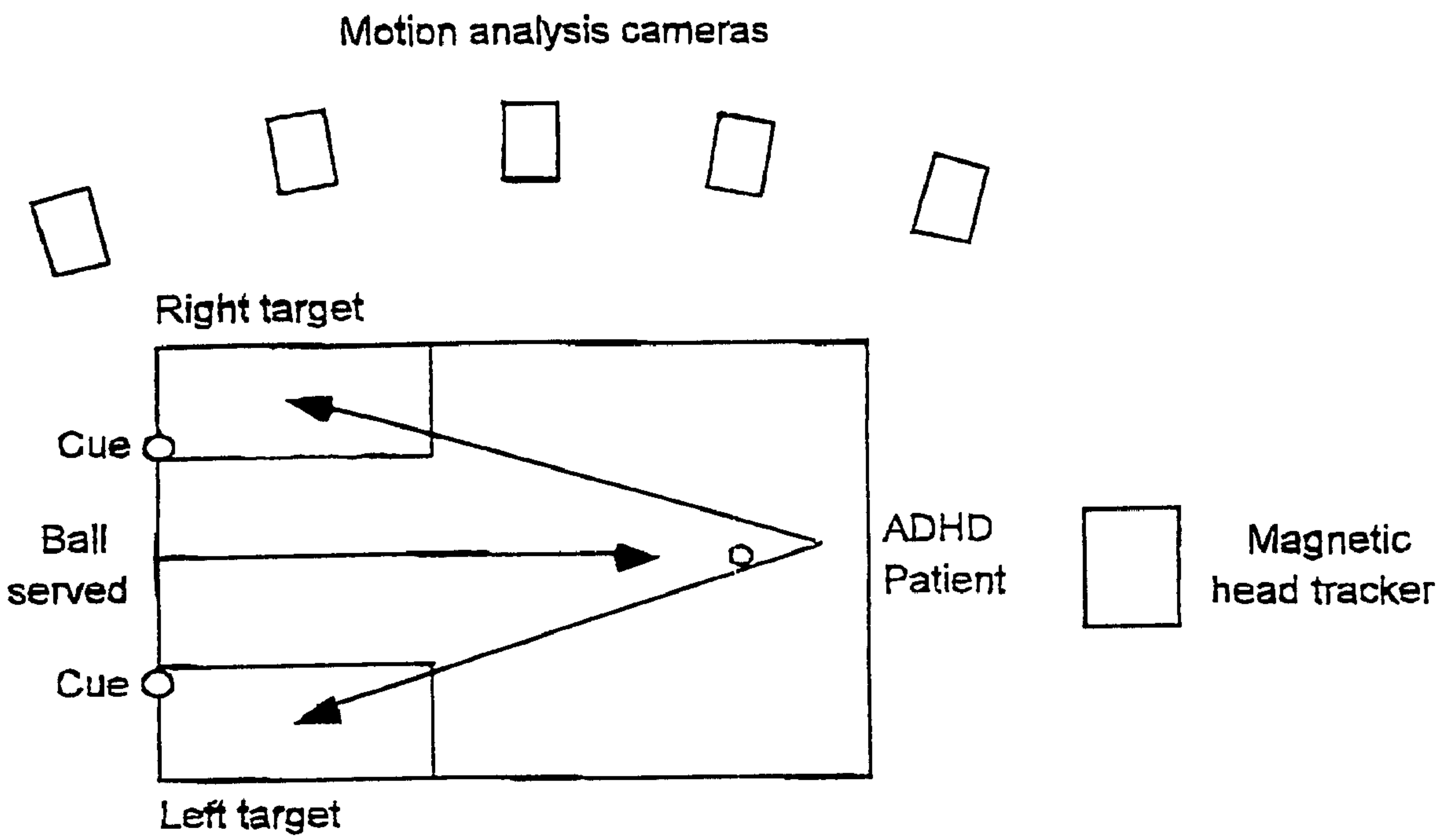
(54) Titre : DETECTEUR DE L'HYPERACTIVITE AVEC DEFICIT DE L'ATTENTION
(54) Title: ATTENTION DEFICIT HYPERACTIVITY DISORDER DETECTOR




(57) Abrégé/Abstract:
An apparatus for assessing the Attention Deficit Disorder condition of a person by measuring the "quiet eye" characteristics of the person, and having, a mobile gaze tracker, means for tracking the orientation of the gaze tracker, a test object, means for detecting motion of the gaze of the person and of the test object, means for recording information from the gaze tracker, orientation tracking means and motion detecting means, and, a programmable computer programmed to process the information from the gaze tracker, orientation tracking means and motion detecting means, wherein the gaze of the person relative to the test object may be determined. Also disclosed is a method of assessing the Attention Deficit Disorder condition of a person by means of the apparatus described.

## ABSTRACT OF THE DISCLOSURE

An apparatus for assessing the Attention Deficit Disorder condition of a person by measuring the " quiet eye" characteristics of the person, and having, a mobile gaze tracker, means for tracking the orientation of the gaze tracker, a test object, means for detecting motion of the gaze of the person and of the test object, means for recording information from the gaze tracker, orientation tracking means and motion detecting means, and, a programmable computer programmed to process the information from the gaze tracker, orientation tracking means and motion detecting means, wherein the gaze of the person relative to the test object may be determined. Also disclosed is a method of assessing the Attention Deficit Disorder condition of a person by means of the apparatus described.

## FIELD OF THE INVENTION

The present invention is concerned with non-invasive methods for diagnosing Attention Deficit/Hyperactivity Disorder or ADHD and is particularly directed to detecting deficiencies in visual tracking through measurement of a variable called "quiet eye' (Vickers, 1996) as a method of diagnosis.

## BACKGROUND OF THE INVENTION

ADHD is defined as a "persistent pattern of inattention and/or hyperactivity-impulsivity that is more frequent and severe than is typically observed in individuals at a comparable level of development" (DSM IV, 1994, p. 78). There are three forms of ADHD listed in DSM 1V. Those diagnosed with primary attention (ADHD - PI) deficit are unable to sustain attention on relevant objects and events in their environment. Those with primary hyperactivity deficit (ADHD-H) have inordinately high levels of impulsiveness in motor behaviour. Combined (ADHD-C) type ADHD exhibits deficits in both attention and hyperactivity.

Diagnoses of ADHD has grown to epidemic proportions (Barkley, 1998; Diller, 1998), yet there is no universally accepted test for diagnosing the condition. Barkley, (1998, p. 227) states that " the current clinical view of ADHD is purely descriptive, describing as it does the two behavioural deficits (inattention and hyperactivity-impulsivity) that are believed to comprise the disorder". A clinical diagnosis of ADHD is currently made using subjective methods such as interviews and questionnaires between the parent, physician, teacher and psychologist. A universally prescribed treatment for ADHD is methylphenidate (MPH) and other CNS stimulant drugs which go by the trade names of Ritalin or

Dexedrine. Methylphenidate is a mild CNS stimulant that is taken orally and peak plasma concentrations of 10.8 and 7.8 ng/mL are observed on average, 2-4 hours after administration depending on the type of drug taken; 78 to 97% of the dose is excreted in the urine and 1 to 3% in the feces in the form of metabolites within 48 to 96 hours.

Ritalin and related drugs reportedly boost the capacity to inhibit and regulate impulsive behaviour and have been reported to improve the behaviour of children in school related tasks over the short term (Barkley, 1998c). MPH and related drugs are administered in a high percentage of ADHD cases due to reported benefits in reducing impulsive behaviour and improving school performance (Elia, Ambrosini & Rapoport, 1999). Losier, McGrath & Klein (1996) in a meta analysis of 26 studies using the continuous performance (CPT) test that measure attention and vigilance, found that children treated with MPH had statistically significant reductions in the rate of errors but overall made significantly more errors than normal children. Upwards of 1.5 million American children took Ritalin during the early 1990's (Safer, Zito & Fine, 1996). Diller (1998) estimated that this number had increased to 3.5 million children and adults by 1996 and an additional 1.4 million were using other medications, such as Dexedrine. Ritalin use in Canada quadrupled between 1990 and 1996 (Diller). A recent report in the New England Journal of Medicine summarized current thinking on MPH: " methylphenidate and dextroamphetamine are well-established safe drugs for persons with this disorder and are the treatments of choice" (Elia et al, 1999, p. 780).

What is puzzling about ADHD is that reported deficits in attention have not been empirically established - "an actual deficit in attention in children with ADHD has not been found" (Barkley, 1998, p. 227). Barkley states that "if attention is thought of as the perception, filtering, selecting and processing of information - in other words involving the 'input' side of the brain - then research on ADHD has not reliably documented such a deficit". The underlying reason for attentional problems therefore remain unknown.

Some research has been carried out exploring the relationship between the'output' or motor control side of the behaviour and ADHD. Piek et al (1999, p. 159) investigated boys with ADHD-PI and ADHD-C, matched on age and verbal IQ on measures of motor coordination. The severity of children's inattentive symptomatology was found to be a significant predictor of motor co-ordination difficulties. Other researchers have found that the relevance of the task to real world situations is also a key factor in effective research on ADHD. Often the tasks used to study ADHD lack relevance to any performed in real life settings. A key to diagnosing ADHD therefore may lie in measuring visual attention during the active performance of a real world motor task. This patent application shows that the detection and measurement of quiet eye, a visual attention variable, provides an objective and valid measure of ADHD. The key to the diagnosis of ADHD is measurement of quiet eye during the performance of a real world perceptual motor skill.

Quiet eye (QE)

During the performance of a motor skill it is important to detect relevant cues and maintain attention on these prior to the performance of the skill (Schmidt, 1991). Quiet eye (QE) is a measure of the location, onset, offset and duration of a fixation or tracking gaze behaviour recorded while a motor skill is performed. This patent application show how QE is recorded using a light mobile eye tracker interfaced to external cameras that record the physical movements of the subject simultaneously. During QE, fixation or tracking is maintained on a specific location or object in space, with onset in advance of movement initiation or the impulse phase of the movement.

QE has been determined in a wide range of motor activities, including basketball (Vickers, 1996a; 1996b), billiards, (Frehlich, Singer & Williams, 1998), darts (Vickers, Rodrigues & Edworthy, 1999), rifle shooting (Murray et al, 1999; Vickers, Williams, Rodrigues, Hillis & Coyne, 1999) and volleyball (Vickers & Adolphe, 1997). In each of these studies, expert performers were found to have an earlier onset of QE, a longer fixation or tracking duration and later offset than non-experts. When time is experimentally constrained during the preparation phase of a movement, QE duration has been found to be reduced and accuracy impaired (Frehlich, Singer & Williams, 1998; Rodrigues & Vickers, in progress).

Research on persons with ADHD (Vickers, Rodrigues & Brown, in progress) has shown they have a significantly impaired ability to maintain pursuit tracking on a moving ball. The task was a modified table tennis task. The subject had to detect the ball in space and maintain tracking prior to contact. Quiet eye was that portion of ball tracking that occurred prior to the forward movement of the arm and racquet to hit the ball. Figure 1 shows the pursuit tracking behaviour of a normal subject, aged 13. Normal behaviour in this task as performed by normal adults and adolescents shows that they detect the ball early and track it over about half of total flight time. Figure 2 shows the tracking behaviour of a male adolescent, aged 13, with ADHD-PI. Evident is an inability to maintain tracking on the ball. Figure 3 shows a significant difference in QE tracking duration of ADHD-PI, while on and off MPH, as compared to age matched Normal controls.

## IN THE DRAWINGS

Figure 1. Pursuit tracking on the ball of a normal subject in table tennis during hits (solid line) and misses (dotted). A visual angle of zero meant the eye gaze was on the ball.

Figure 2. Pursuit tracking of a ADHD subject in table tennis during hits (solid line) and misses (dotted). Note that this subject was unable to track the ball over most of its flight.

Figure 3. QE duration (measured as a percent of total flight time of the ball) of ADHD and Normals showing a significantly shorter duration of QE in those diagnosed with ADHD-PI.

Figure 4. Top view of a modified table tennis table showing the ADHD test subject, right and left cue lights, direction of ball serve and target areas to which the ball must be hit. The magnetic head tracker and motion analysis cameras are also shown.

Figure 5. A frame of Vision-In-Action (VIA) data. Scene A shows the test subject's gaze (the while cursor) tracking near to ball. Scene B shows the subjects about to hit the ball. Scene C shows the eye of the subjects and x/y co-ordinates indicating the centre of the pupil and corneal reflection.

Figure 6. Setup of MHT with transmitter, receiver and control unit.

Figure 7. Representation of visual angle between line of gaze and ball edge (A), gaze and x-axis of the transmitter coordinate system (B), and the angle between arm (elbow-wrist segment) and x-axis of transmitter coordinate system (C).

## DESCRIPTION OF A SPECIFIC EMBODIMENT

Two tests have been developed to diagnose ADHD, the table tennis test shown in Figure 4, which is suitable for older test subjects, and a table hockey test suitable for older and younger test subjects. The table tennis task is described here, but a similar technology, software and procedures are used in the table hockey task.

Figure 4 shows the modified table tennis table, fitted with cue lights and right and left target areas. A table tennis ball is delivered to the test subject using an device that directs the ball down the middle of the table at a moderate speed (flight time of approximately 800 ms). The target areas are large and rectangular and are placed on each corner of the server's side of the table. They are large enough to be easily hit. The right and left target area is cued by a set of lights placed near each target area. Test subjects use their preferred hand and technique of hitting. Two conditions are used in each test protocol. During the Easy condition, the cue light is illuminated two seconds before the ball is served thereby giving the test subject ample time to respond. During the Hard condition, the cue light is illuminated 300 ms after the serve thus leaving only 600 ms for the test subject to respond.

Description of Technology That Records Quiet Eye

Eye movements, arm movements and flight of the ball are measured simultaneously using three integrated systems: The Vision-in-Action (VIA) system (Vickers, 1996a, 1998a, 1998b), magnetic head tracker (MHT) and motion analysis system (MAS).

The Vision-In-Action or VIA system integrates a mobile eye tracker, an external body movement camera, a time code generator and video mixers to record the test subjects' gaze, motor and ocular behavior. The VIA system is used to 1) detect the onset, duration and offset of quiet eye, 2) calibrate the test subject, 3) monitor accuracy of the data collection, 4) provide diagnostic information to test subjects , and 5) provide a treatment modality to improve visual tracking and attention.
A frame of VIA data as collected in ADHD is shown in Figure 5. Scene A was recorded by the scene camera on the test subject's eye tracker and shows the location of gaze relative to the table tennis environment. Location of gaze is indicated by the white cursor. Scene B shows the movements of the ADHD test subject as recorded by the external body movement camera. Scene C was recorded by the eye camera on the eye tracker and shows the test subject's eye and horizontal and vertical axes of the pupil and CR centroids. All three images were collected simultaneously and integrated at a video output frequency of 30 Hz (or 33.33 ms per frame

The magnetic head tracker or MHT is needed to determine the location of the gaze relative to the ball. MHT was developed by Ascension Technologies (Model Flock of Birds) and tracks the three-dimensional position and orientation of the eye tracker relative to a transmitter located above and one metre behind the test subject as shown in Figure 6. Position and orientation is determined by transmitting a pulsed DC magnetic field to the receiver on top of the eye tracker. From the measured magnetic field characteristics, the receiver independently computes position and orientation of the head.

MHT has a static positional accuracy of 0.1" (2.54 mm), a positional resolution of 0.03" (0.76 mm), a static angular accuracy of 0.5 degrees, and angular resolution of 0.1 degrees. MHT data was internally combined with the eye tracker data in order to generate line-of-gaze relative to the environment, rather than line-of-gaze related to the helmet. Eye-head integration (EHI) is an expansion of the ASL 501 eye tracker software that enabled this combination. EHI data was updated at 60 Hz, the same frequency as the eye tracker. EHI output the two-dimensional coordinates of the intersection point between the line-of-gaze and a plane of interest, defined in this study as the plane that coincides with the table tennis table surface. EHI also output three-dimensional position and orientation angles (azimuth, elevation, and roll) of the receiver with respect to the transmitter coordinated system.

Eye and head tracker calibration procedures are fully integrated in software developed for this purpose. Calibration is divided into specification of planes and specification of eye position in space. The planes to be specified to the software are the table surface plane and the calibration plane (plane placed on the table surface). Placing the receiver in a wand with a laser pointer at one end and a gimbal attached to the other, the specifications were made as follows. The gimbal allowed motion of the wand in three dimensions relative to the center of the transmitter, the origin of the MHT coordinate system. By pointing the laser spot in three points of each plane and by using previously measured distances from the transmitter to those same points, software calibrated the receiver signals to the three dimensional space where the experimental task took place.

Before starting the specification of eye positions, the receiver is removed from the wand cup and placed on the top of the helmet and the specification of planes taken. The test subject was fitted with the eye tracker helmet and calibrated to nine points on the calibration plane. Fine calibration procedures were recorded before and after selected trials to three defined locations on the table tennis surface which coincided with ball trajectory to ensure maintenance of calibration.

Movements of the ball and arm are detected by a motion analysis (MAS) system which consists of three to six cameras positioned to one side of the table as in Figure 4. Test subjects are fitted with retro-reflective markers attached to the elbow (head of radius) and wrist (ulnar head) of their dominant hand to allow digital processing of marker recognition by the cameras of the motion analysis system (MAS). High-speed video cameras (180 Hz) and software capture video images from each camera, recognized retro-reflective markers on each camera image, and reconstructed the three-dimensional position of the markers in the space thus providing three-dimensional position data of arm and ball flight. Synchronization of all components of the system was achieved by electrical pulses sent simultaneously to a central control box.

Protocol.

The test subject is first allowed to practice the task until comfortable, about ten minutes. The eye tracker is then fitted and the test subject calibrated to nine points in space that coincide with the table surface. A second fine calibration procedure is carried out during testing to three points (1,2,3) on the table located along the path of the ball.

Two tests are used: (Easy, Hard). In the easy condition the test subject a target cue light comes on two seconds before the ball is served. In the hard condition, the target cue comes on 300 ms after the ball is served. Trials are intermixed using a Latin square design (Maxwell & Delaney, 1990) to minimize order effects. Catch trials are used in order to avoid guessing (Davids, 1988; Schmidt & Lee, 1999).

Data Analysis

A software program has been written in Matlab to handle data smoothing, interpolation, coordinate system transformation and calculation of angles of interest. Elbow, wrist, head positions and head orientation data are smoothed with forth order Butterworth filter at 5 Hz. Ball position data is smoothed with the same filter at 30 Hz. Interpolation is necessary to transform data originated in EHI from 60 Hz to 180 Hz. This procedure is used to generate the final data points in different intervals to match the MAS data acquisition frequency. Linear interpolation calculates the gaze data points to coincide with an imaginary line between each pair of original data points; this is appropriate for gaze data due to the speed and abrupt changes in eye position. Spline interpolation estimated new data points for head movement according to a smoother curve that fit the original data; this is appropriate for head data due to the relatively slow nature of head movements and their smooth trajectories.

To calculate the angles of interest underlying specification of quiet eye, data in the table and the cube coordinate systems are transformed (translated and rotated) to the transmitter coordinate system. This transformations uses a Matlab routine based on Soederkvist and Wedin's (1993) algorithm to determine rigid body rotations and translations. To test the accuracy of these transformations, measurements of three points on the table (distant from each other and similar to those used in fine calibration in the three coordinate systems are used: cube calibration (MAS), table and transmitter (gimbal laser and ruler). The root mean squared value of residuals resulting of the transformation from cube to transmitter coordinate system was 0.81 cm, and from table to transmitter coordinate system was 0.96 cm. These transformations were then performed for all calibration settings. Once all data are in the same coordinate system, three angles are calculated as shown in Figure 7A, 7B and 7C. Figure 7A shows the visual angle between line of gaze and ball edge. Figure 7B shows the visual angle between the line of gaze and x-axis of the transmitter coordinate system. Figure 7C presents the angle between the arm segment elbow to wrist and x-axis of transmitter coordinate system.

QE was defined as the visual angle between the line of gaze and the ball edge was maintained stable within three degrees of visual angle for at least 100 ms. The three degree limit was derived from Ripoll & Fleurance and Vickers & Adolphe. Stability of 100 ms on the ball was based on a criterion adapted from Helsen et al. (1998). Onset occurred prior to the initiation of MT and offset occurred when the gaze was off the ball for 100 ms.

Both absolute (millisecond) and relative (percent) time are determined. A normalization procedure was applied to the data relative to total trial duration (*rt%*). Thus every trial had its onset transformed to *rt %0* and offset to *100%rt* (ball-bat contact). Each point in time represented a proportion to the total time (Schmidt & Lee, 1999). Relative time is the stronger of the two measures for QE as it takes into account any variance in terms of ball light. The normalization of time of each data point was proportionally calculated using the following formula:

$$\text{Relative Time} = \frac{(\text{absolute time of data point} - \text{absolute time of trial onset}) * 100}{\text{absolute time of trial offset} - \text{absolute time of trial onset}}$$

With these data analysis procedures, results similar to those shown in Figures 1 to 4 are produced, from which a diagnosis of ADHD is derived.

Relevance Of The Quiet Eye Diagnostic Test

ADHD is an area of investigation replete with subjective methods of diagnosis, an incomplete understanding of the effects of medication, conflicting results in terms of the research especially as it applies to attention and confusion in terms of whether the condition's origins lie at the cognitive or motor level. In order to change this situation, Barkley (1998) has proposed that any solution toward a successful test of ADHD must fulfill the following requirements. First, ADHD test subjects must be shown to have attentional deficits compared to Normals. QE has been shown to differ significantly between ADHD and Normals and is an objective and valid indicator of visual focus and visual attention during performance of a real world task. Second, a test of ADHD must explain the link that exists between poor behaviour inhibition and the sister impairment of inattention. QE defines both visual focus relevant to a critical object as well as a critical body movement, a target directed arm action. Third, any credible test of ADHD must link the two dimensions of hyperactivity-impulsive behaviour and inattention with the concept of executive function. QE measures the detection of appropriate cues from inappropriate and the selection of a correct response from an incorrect. Fourth, a test of ADHD must bridge the literature on ADHD with the larger literature on developmental processes, that is, it must be suited to all age groups from young children to adults. The current test has been used successfully with children, adolescents and adults. Fifth, a test of ADHD must be useful as a scientific tool in explaining what is currently known about ADHD and new phenomena not explored to date. The proposed test fulfills these requirements in two areas: by providing a test which can be used when test subjects are both on and off their medication, as well as a tool that potentially trains QE attention and a resultant improvement in performance.

**The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:**

1. An apparatus for assessing the Attention Deficit Disorder of a person by measuring quiet eye in a person, comprising:

a test object at which the person may gaze;

a mobile gaze tracker;

means for tracking the orientation of the gaze tracker;

means for detecting motion of the gaze of the person and of the test object;

means for recording information from the gaze tracker, orientation tracking means and motion detecting means; and

a programmable computer programmed to process the information from the gaze tracker, orientation tracking means and motion detecting means;

wherein the gaze of the person relative to the test object may be determined.

2. A method of assessing the Attention Deficit Disorder condition of a person by measuring the quiet eye condition of the person by means of apparatus including a mobile gaze tracker, means for tracking the orientation of the gaze tracker, a test object, means for detecting motion of the person and the test object, means for recording information from the gaze tracker, orientation tracking means and motion detecting means, and a programmable computer programmed to process the information from the gaze tracker, orientation tracking means and motion detecting means, and comprising the steps of;

causing the person to gaze at a test object;

tracking the gaze of the person, and detecting the orientation of tracking;

detecting the motion of the test object and the gaze of the person; and,

recording the information detected in a computer, whereby the gaze of the person relative to the test object may be determined.

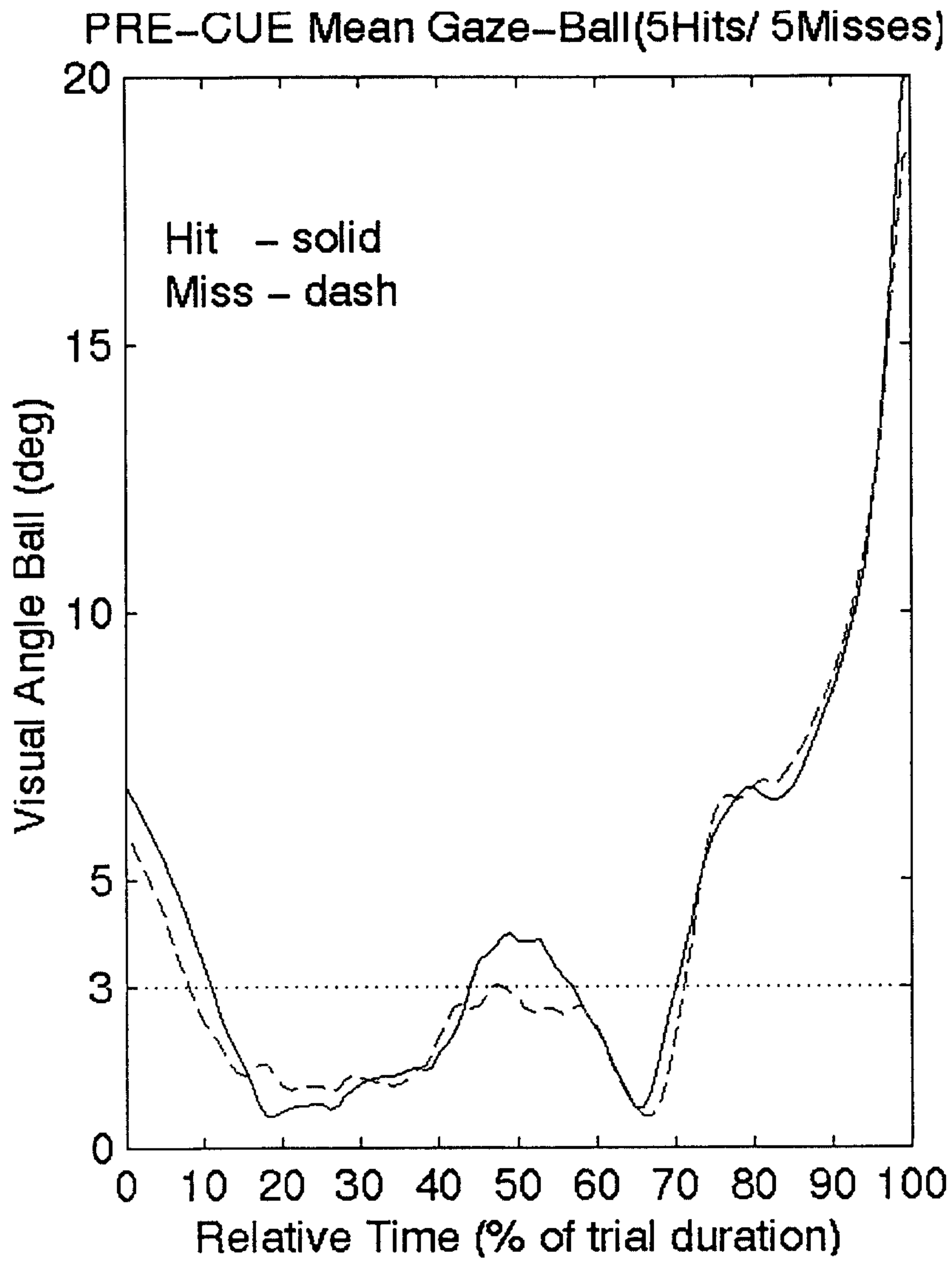

PRE-CUE Mean Gaze-Ball(5Hits/ 5Misses)
Hit - solid
Miss - dash
Visual Angle Ball (deg)
20
15
10
5
3
0
0 10 20 30 40 50 60 70 80 90 100
Relative Time (% of trial duration)

**Fig 1.**

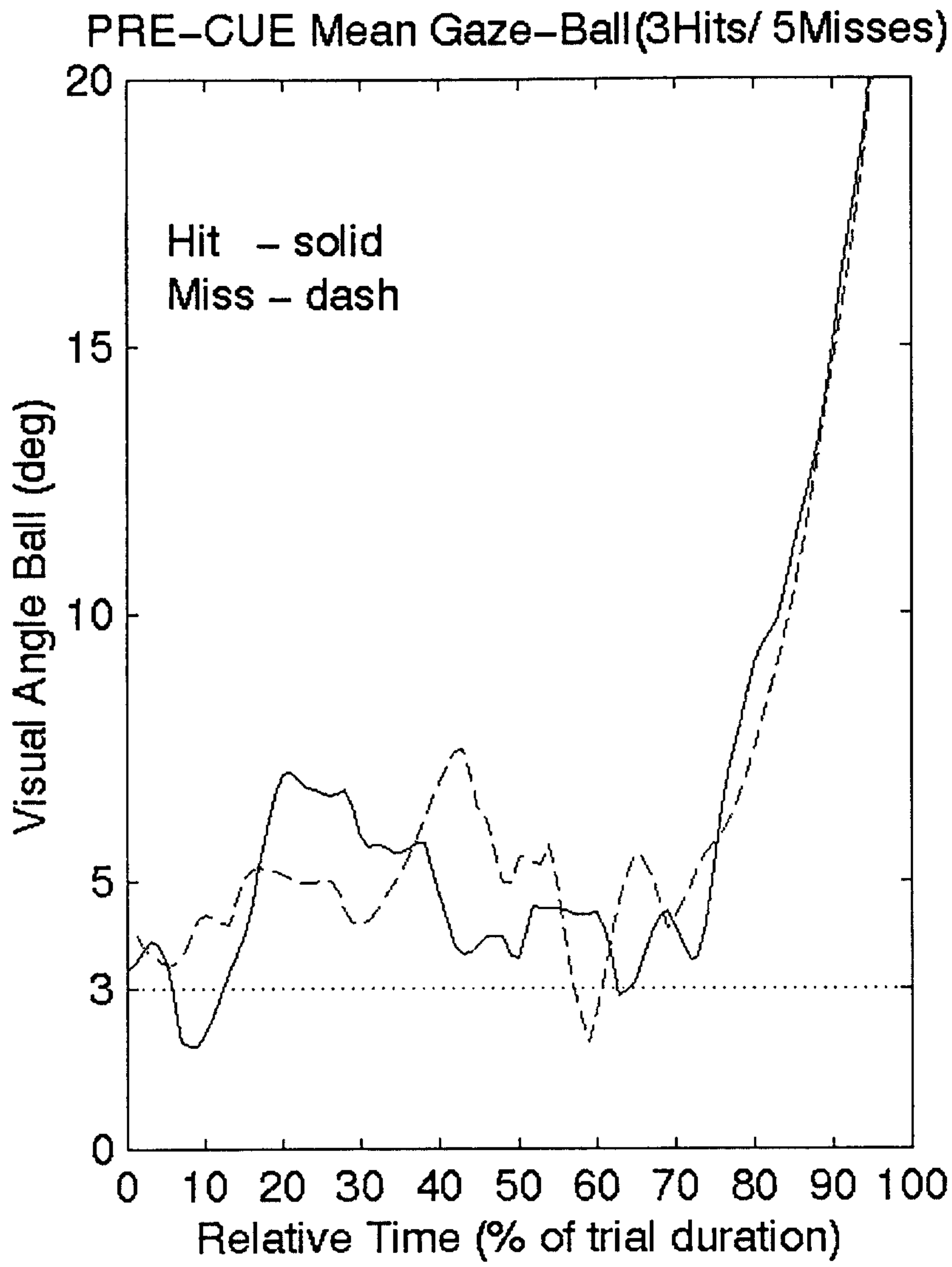

PRE-CUE Mean Gaze-Ball(3Hits/ 5Misses)
Hit - solid
Miss - dash
Visual Angle Ball (deg)
0
3
5
10
15
20
0 10 20 30 40 50 60 70 80 90 100
Relative Time (% of trial duration)

**Fig 2.**

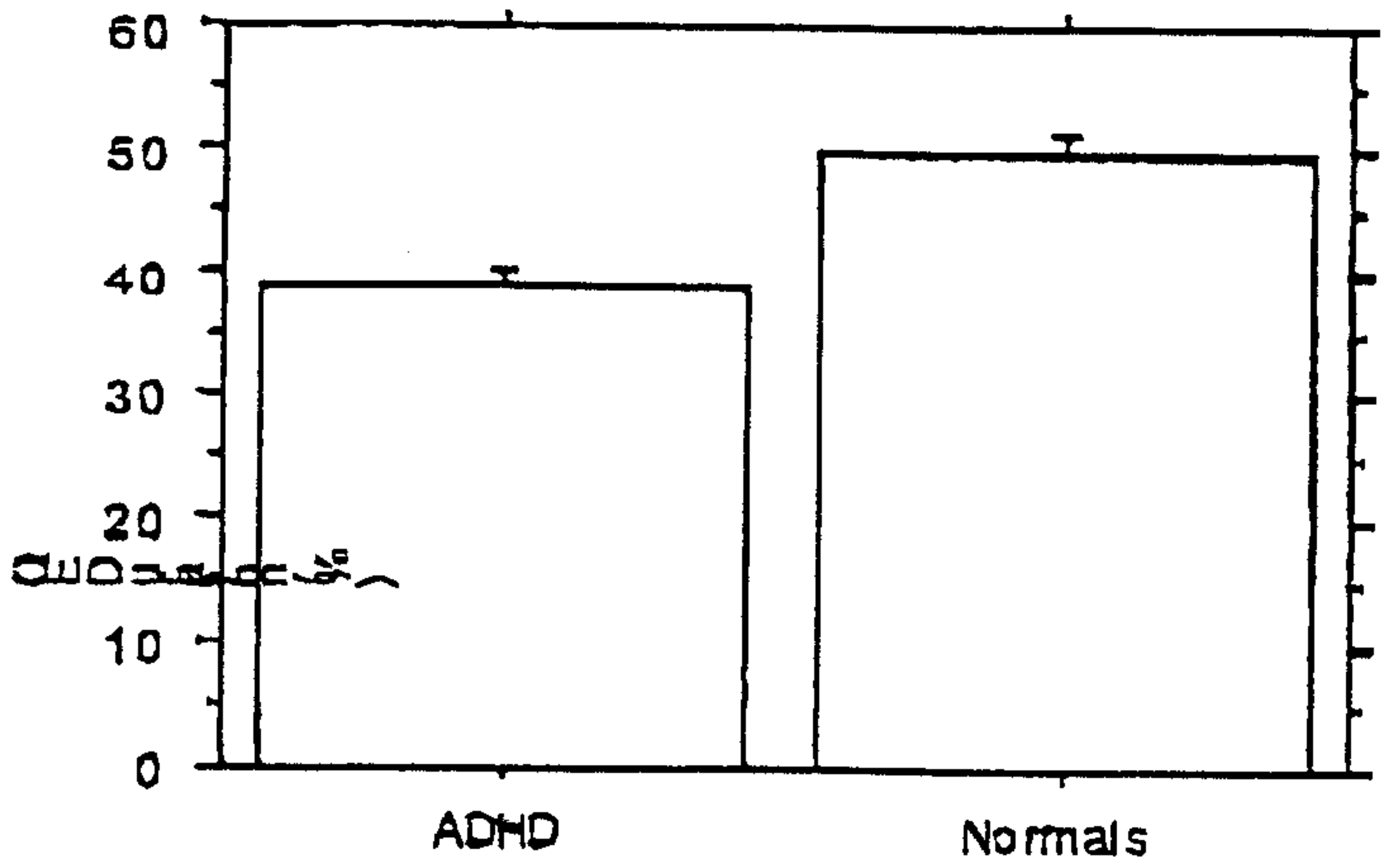

60
50
40
30
20
10
0
ADHD
Normals

Fig 3.

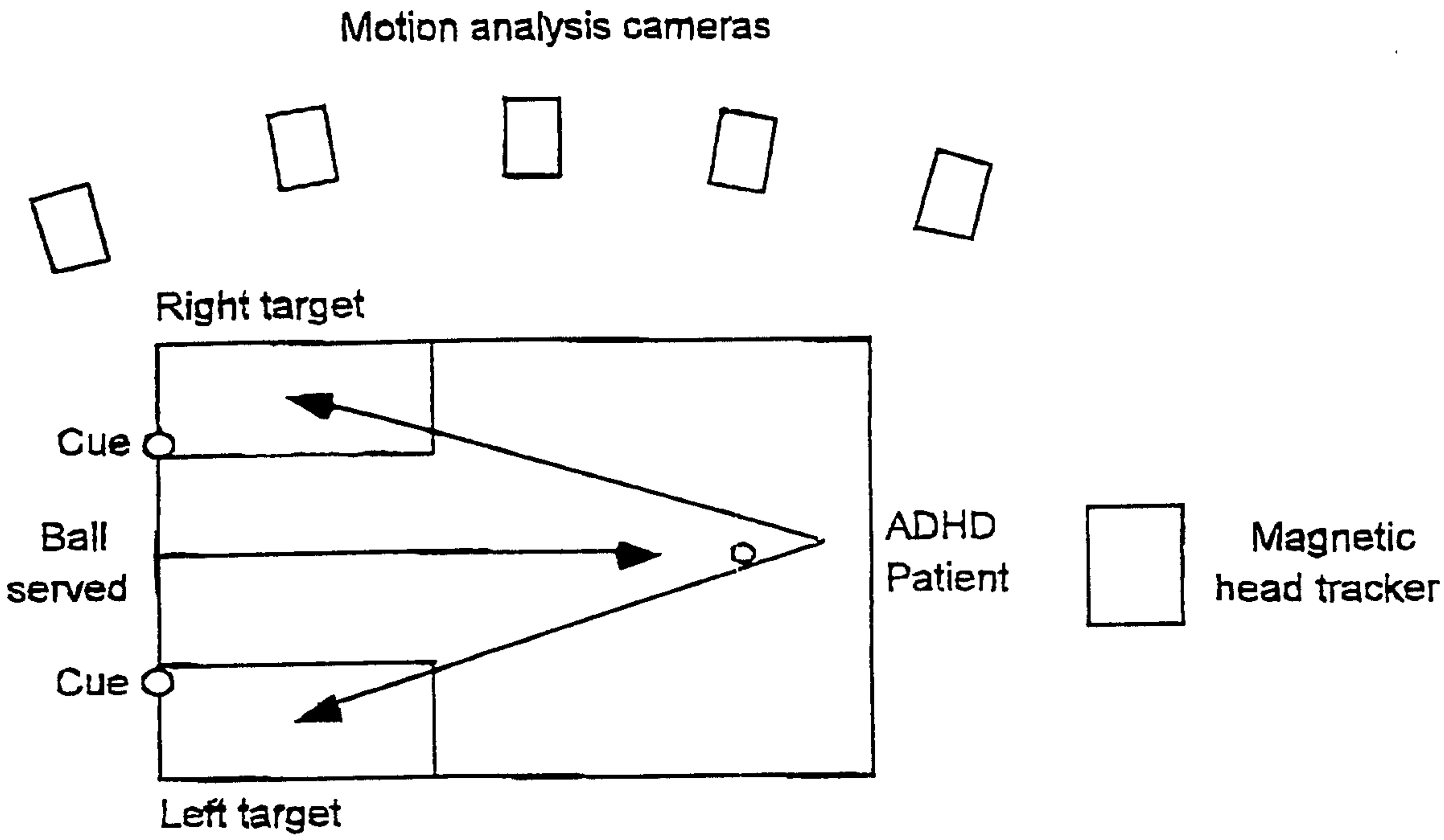

Motion analysis cameras
Right target
Cue
Ball served
Cue
Left target
ADHD Patient
Magnetic head tracker

Fig 4.


C
A
Location of gaze
B
5-18-99 TUE
4:28:41:58 PM

Fig 5.

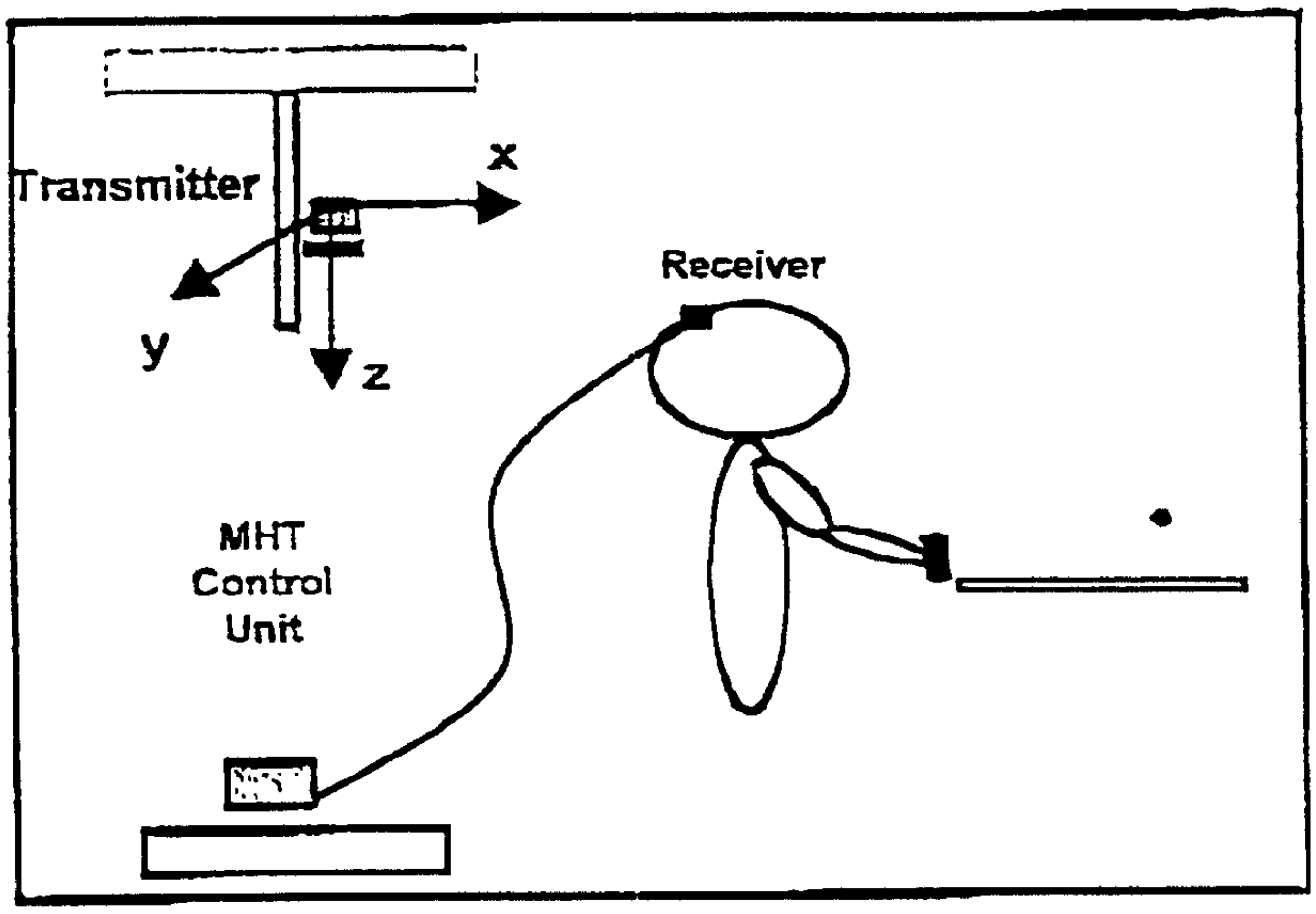

Transmitter
x
y
z
Receiver
MHT
Control
Unit

Fig 6.

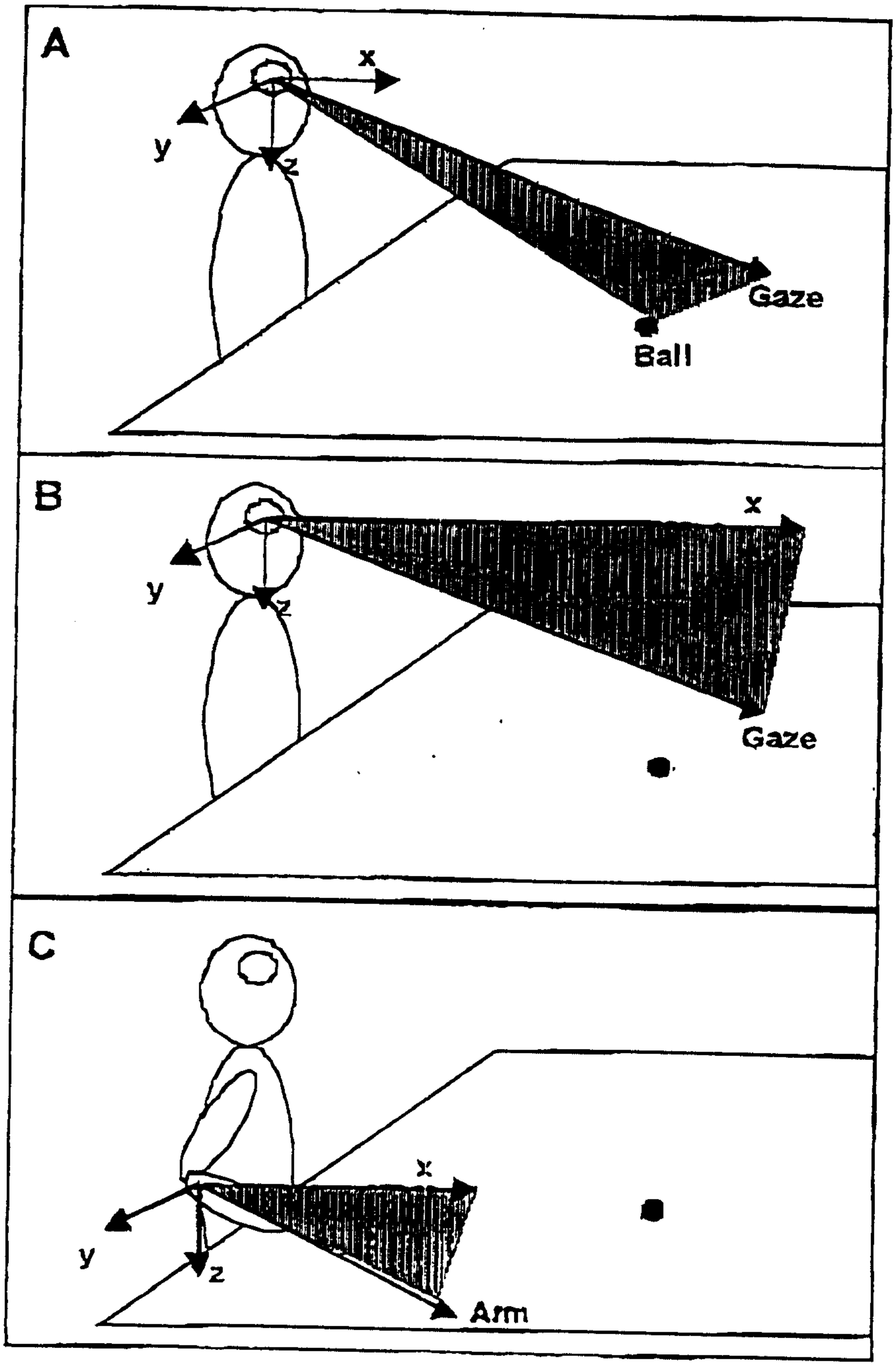
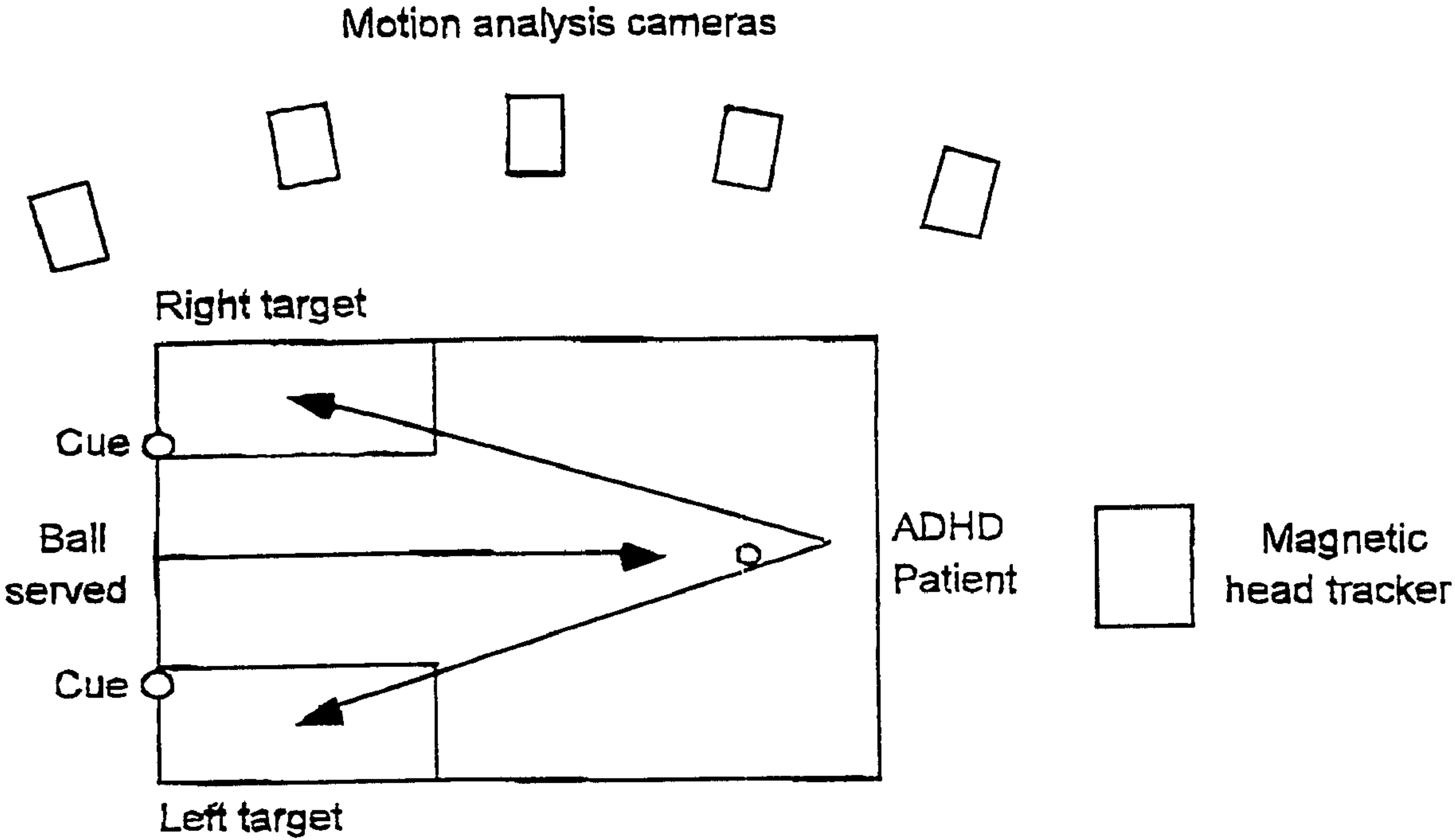



Fig 7.



Motion analysis cameras
Right target
Cue
Ball
served
Cue
Left target
ADHD
Patient
Magnetic
head tracker