Enhancement to the Conditioned Head Turn Technique to Measure Infant Response to Auditory Stimulus

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Abstract

A phonetic recognition and reaction measuring tool is presently in use by sociological and psychological researchers at the University of Washington. The tool makes use of a system known as the Head Turn Technique (HTT). The tool measures the test participant's response to subtle changes in phonetics he or she is hearing by sensing the movement of the participant's attention focus toward the source of the phonetic stimulus. The existing tool has been largely unchanged for five years and may benefit from a technological revision. The tool, as it is, relies heavily upon human interface, which may be contributing to inaccuracy of measurement and limitations in the types and richness of data that are captured. In the existing process, a test administrator manually initiates the event prompting the change in the focus of the subject's attention. The occurrence or non-occurrence of the response is then judged by the test administrator. Computer control is limited to the generation of the phonetic stimulus. The proposed revision includes a laser pointing device and a laser light receptor array, software modification, and revision of the test procedure. The enhancement could add the ability not only to detect the occurrence of the head turn event but also to time various aspects of the event. Computer software would trace the path of the laser pointer's beam as the head is moved and hence the precision with which the head is moved. It could also measure the divergence between the orientation of the head and the focus of attention.

Discussion of the Head Turn Technique in Its Present Form

The present iteration of the HTT test process was developed for use in measuring infant and toddler response to subtle changes in the phonetic composition of sounds to which the child is being exposed [1, 2]. Figure 1 presents a plan of the test layout showing one of the team members and the test participant. Figure 1 does not show the second test team member, since that member is not present at the test location but administers the test from a remote location. As can be seen by examination of Figure 1, the toy waver is situated approximately 30 to 45 degrees to the participant's right, while the loudspeaker and display are 30 to 45 degrees to the participant's left.

The process presently includes two test team members in addition to the test participant. The team is comprised of the test administrator and the toy waver. The test administrator's function is to manipulate the computer that is in control of the generation of the phonetic stream and to record the response of the participant. The phonetic stream is composed of a sequence of phonetic sounds that are presented as single syllables to the participant through a loudspeaker. In the sequence, a phonetic is repeated several times. At a given point in the sequence, the phonetic undergoes a subtle change hereinafter known as a phonetic change event. As an example, the phonetic "Lah" may be repeated until the test administrator initiates the phonetic change event. At this point, the phonetic "Bah" is repeated three times. This phonetic sequence may be better understood by examining Figure 5. The goal of the test is to measure the participant's reaction to the phonetic change event. Participant gaze reorientation, coincident with the phonetic change event toward the speaker from which the sounds are emanating, is recorded by the test administrator as a successful detection by the participant that a phonetic change event has occurred.

The toy waver's function is to attract and maintain the attention of the participant by use of actions and gestures with the toy. In addition to these two members, the parent of the infant or toddler participant may be present to reduce tension in the participant. The test administrator is not visible to the toy waver, the participant, or the parent of the participant. In this way, neither the toy waver nor the parent will know when the phonetic change event will take place. This is important, since such pre-awareness might prompt the parent or toy waver to anticipate the movement of the participant's head with an inadvertent glance in the direction of the loudspeaker. Such actions have been demonstrated to be sensed by participants, a phenomenon referred to as gaze following [3]. Such gaze following would create an undesired control variable that would have a contaminating effect on the outcome of the test.

Test participants are males or females not younger than the age of six months. In the present test process, the infant or toddler participant is placed in the parent's lap in close proximity to the toy waver and to the loudspeaker and display. The toy waver maintains the concentration of the participant by showing the participant a toy, generally a stuffed animal. Simultaneously, the computer software used to administer the test causes an audible repetition of a syllable which is common in the English language. An example is "Lah." The phonetic "Lah" is repeated at a rate of approximately once per two seconds. At an appropriate moment, the test administrator, through computer control, initiates the phonetic change event, at which point the repeated phonetic changes from "Lah" to another phonetic, "Bah," for example. The changed sound is repeated three times, and then the software reverts back to the original phonetic. With the change in the phonetic, the display that is on the same axis as the loudspeaker will present a picture of a stuffed animal. In this way the participant is presented with a pleasing stimulus as a reward for having noticed a change in the syllable that is being repeated.

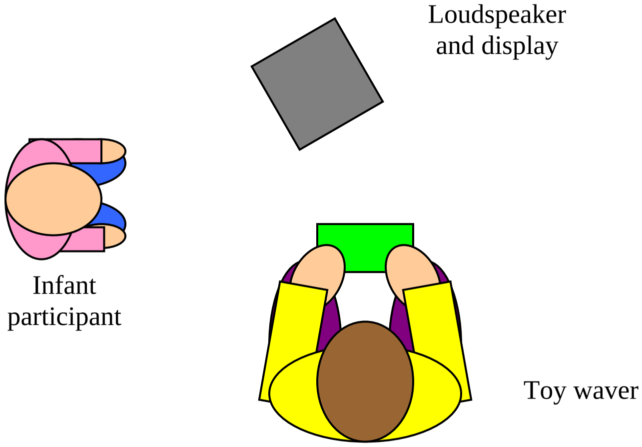

Figure 1: Plan of Test Process Layout

As depicted in Figure 2, the function of the toy waver is to maintain the concentration of the participant for the duration of the test. In this figure, the child's attention is being attracted by the toy waver, and the focus of the child's gaze reflects the child's attention to the toy waver's activities [4]. This referent attention associated with gaze has been demonstrated in infants as young as six months [5]. The child's gaze is fixed upon the toy, and the head position reflects the attention of the child. While the child is watching the toy waver, the loudspeaker emits the repeated phonetic: "…Lah…Lah…Lah…"

When the test administrator is confident that the child's attention is properly fixed on the toy, he or she initiates the phonetic change event. Simultaneous with this change in the phonetic, the monitor presents an image of a stuffed animal similar to the one held by the toy waver. The initiation of this image is delayed slightly so that it is clear that the change in the participant's focus of attention was caused by the change in sound and not by the occurrence of the image on the display.

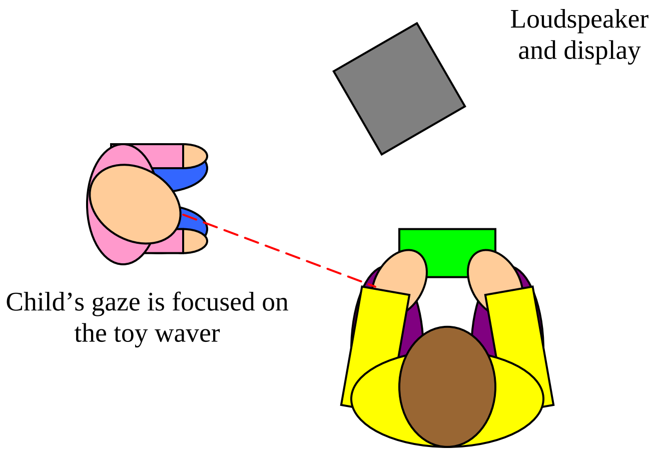

Figure 2: Participant's Gaze and Attention Focused on the Toy

The participant's attention shifts to the loudspeaker and display at the moment that the participant senses the phonetic change event. This realignment of the attention axis or the absence of same is observed by the test administrator. Successful detection of the phonetic change is indicated by a shift in the participant's gaze toward the loudspeaker and display as depicted in Figure 3. This reorientation of gaze in known as the head turn event.

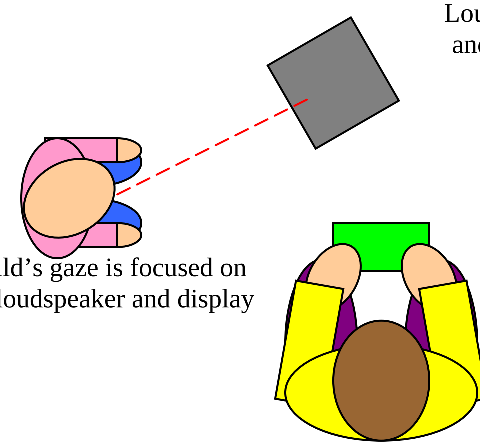

Figure 3: Participant's Gaze and Attention Focused on the Display

It is up to the test administrator to record that the head turn event has been executed. The test administrator records occurrence or nonoccurrence only. There is no ability to fix in time the occurrence of the phonetic change event or the head turn event.

The Proposed Revision

This conceptual article presents a revision of the HTT. The revision could enhance observations in four ways:

1. It has the potential to provide the ability to measure the time interval between the phonetic change event and the beginning of the head turn event.
2. It has the potential to measure the time interval between the beginning of the head turn event and the end of the head turn event. (These two intervals are summed to produce the total time interval between initiation of the phonetic change event and the completion of the head turn event.)
3. It has the potential to trace and store the path of head pointing during the head turn sequence.
4. It has the potential to measure the divergence between the orientation of the head and the focus of attention.

Discussion of the Proposed Revisions

The revision makes use of a system that permits accurate measurement of the orientation of the head as well as timing of the head turn test sequence. It embodies two hardware elements not in use in the present system design. These hardware elements include a laser pointing device (LPD) embedded in a cap that is worn by the participant and a laser receptor array (LRA), which detects the direction in which the LPD is oriented and then generates two binary numbers corresponding to that direction. The first binary number corresponds to the horizontal orientation, while the second number corresponds to the vertical orientation. The enhancement also embodies a software element that converts the binary number generated by the LRA to a virtual location, which is stored by the administrator's computer and which is presented on the monitor that the administrator is using. These revisions necessitate several procedural additions and modifications to the test procedure.

Design Revisions – The Laser Pointing Device (LPD)

The infant and/or toddler participant will wear a knitted or similar cap to which an LPD is fixed. Such devices are available at minimal cost. They are small and light. The most difficult aspect of LPD design is its packaging and mounting. An LPD resembles a shorter version of an instructor's laser pointer. Such a device will be mounted to the participant's cap. Since the device is small in size and light in weight and since infants and toddlers are accustomed to wearing caps, it is anticipated that the LPD will create no distraction to the participant. It is well known that such devices emit a finely focused light in the visible spectrum, a bright red dot. This red dot might serve to distract the participant if it is visible to the participant. To overcome this shortcoming, it is proposed that the LPD be oriented rearward so that its emitted light is out of the field of view of the participant.

Design Revisions – The Laser Receptor Array (LRA)

The second hardware addition is the LRA. Such an array resembles a segment of the surface of a sphere that measures 60 degrees vertical by 120 degrees horizontal. The complete sphere has a diameter of 2–3 meters. On this surface are mounted multiple receptor elements in a square matrix or square grid. The distance between elements (element density) is dictated by the beam width of the laser emitter and the desired resolution of the path measurement discussed below. In the present configuration, the participant is held on the parent's lap. Since the laser is directed rearward, the presence of the parent behind the participant's head would block the laser; consequently, under the revised design, the parent will not be present at the test location. As shown in Figure 4, nothing can be interposed between the participant and the LRA; consequently, the participant may not sit on the parent's lap.

The distance between the participant and the LRA is anticipated to be between 1–1.5 meters. The shape and size of the LRA must be such that an element is available to be illuminated by the LPD at all potential orientations of the head of the participant regardless of the attention source. The function of the array is to create two binary numbers for processing by the software routine that is resident in the administrator's computer. As revealed previously, the two numbers will be generated by the array based upon which element is illuminated in the horizontal and the vertical axis. The representative binary numbers will be transferred to the computer that is being used to control the test. The layout of the revision is presented in Figure 4.

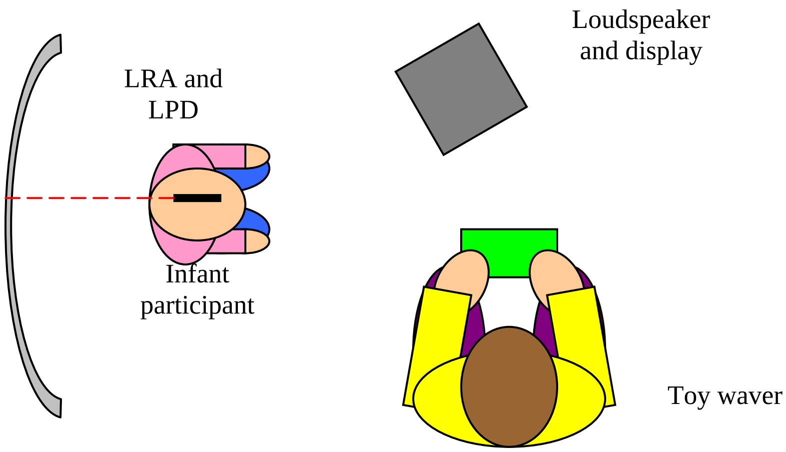

Figure 4: Revised Test System Layout

Design Revisions – Software

In the existing test configuration, the software is used to initiate the change in phonetics. Under the revision, it is necessary to modify this software so as to add several capabilities, as follows:

1. The revised software must embody a graphic user interface (GUI) that serves as a "dashboard" for the test administrator. This dashboard must give the administrator control over those functions necessary to perform the test, store the results, display the test as it occurs, replay the test, and mathematically analyze the test from a time/event standpoint.
2. The revised software must be able to receive and process the binary numbers from the LRA to display the orientation of the laser dot on the computer monitor and to store that location in memory.
3. The revised software must be capable of executing all of the existing functions plus all of the additional functions of the revised test procedure. These functions include phonetic change event initiation, graphic presentation of the orientation and movement of the head in the appropriate format, control of the phonetic that is broadcast via the loudspeaker, control of the presentation of the toy on the participant's monitor, storage of data that is captured during the test, replay of stored test results, and the ability to process test results such that the beginning and end of the head turn event can be established.

As a starting point on software and GUI development, the ability to capture the time measured in seconds at which the phonetic change event occurs is proposed. This time event (designated "T1") will begin the time interval measurement sequence. The occurrence of the phonetic change initiation will start a timer within the software. Resolution of the timer should be at least three decimal places, providing the ability to measure time with an accuracy of .001 second. A time designation “T2” will be given to the time at which the orientation of the head begins its excursion from its initial position (focused on the toy waver’s activity) to its new attention. Finally, the designation “T3” is given to the time at which the head is fixed at its terminal position (focused on the loudspeaker and monitor). Figure 5 may be examined to provide a better understanding of the time sequence.

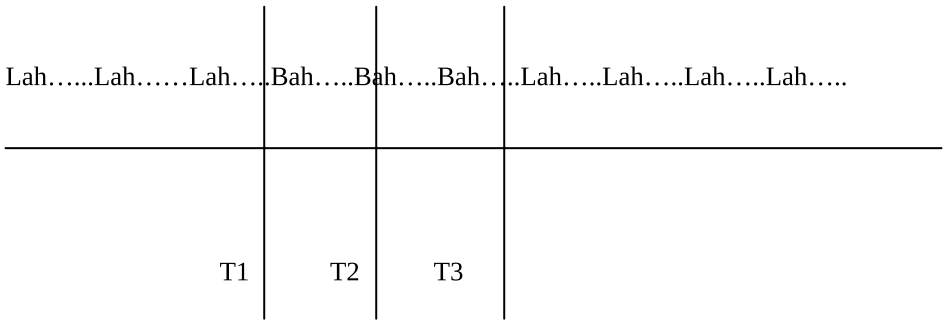

Figure 5: Timeline for Phonetic Change and Head Turn Occurrence

In the interest of clarity, the following explanation is presented. As the test sequence begins, the test administrator will direct the toy waver to begin the activities that are intended to hold the attention of the test participant. The participant’s attention, indicated by gaze, will focus on the toy and toy waver. The control computer will direct a phonetic syllable to the loudspeaker. The software must have the ability to record the output of the LRA, which will indicate that the participant is paying attention to the toy and toy waver. When the administrator is satisfied that the attention of the participant is attracted to the toy, the administrator will initiate the phonetic change event. The software must have the ability to designate this time as “T1.” The control computer will then direct the new phonetic syllable to the loudspeaker.

As the participant senses the change in phonetic, his or her gaze will begin to reorient toward the loudspeaker and display. The head will begin to shift, reflecting that the participant is intending to shift his or her gaze in the direction of the loudspeaker and display. The test software will sense this change in gaze orientation predicated by a change in the binary numbers that are created by the LRA. The test software routine will designate the instant in time at which the head began to move as “T2.”

The participant’s head will continue to move until it has become fully reoriented in the direction of the loudspeaker and display, at which point it will stop. The output of the LRA will generate two binary numbers that indicate the new head orientation. These numbers will be processed by the control software routine, which will designate the time at which the head stopped as “T3.”

Path

As the head moves from its initial to its terminal position, the LPD will illuminate and activate elements in the array that capture the instantaneous orientation of the head. The LRA will output binary numbers, which will be sent to the control computer for processing in the control software. A subroutine within that software will map this path and display the path on a two-dimensional grid that is part of the GUI, as shown in Figure 6. This map or

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path will essentially be a history of the participant's head movement for the duration of the test. The subroutine will also have the power to store the history of the head movement for statistical processing and for the purpose of replay.

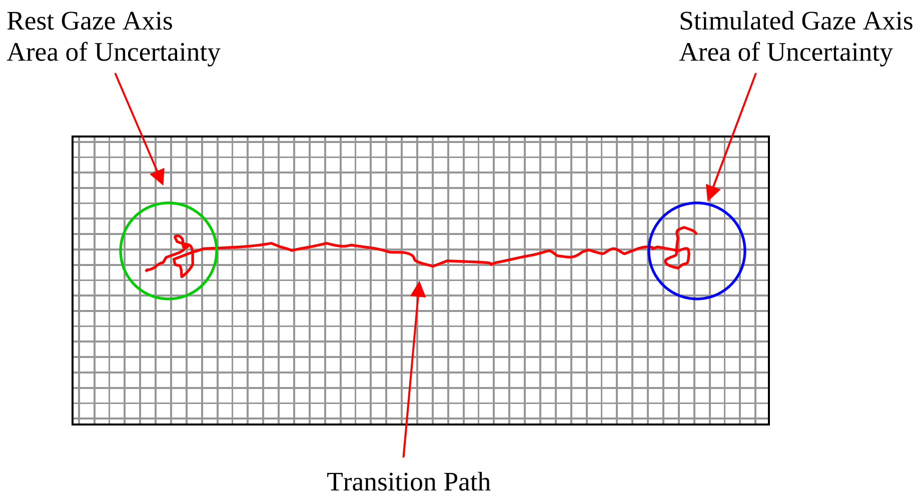

Figure 6: Notional Map or Path as Displayed on the Control Computer as Part of the GUI

Design Revisions – Test Format

Post-revision, the control of the entire test process will be relinquished to the computer and software. The action by the test administrator will be simply to initiate the test immediately after the attention of the participant is focused on the toy waver. Occurrence or non-occurrence of the head turn event would be sensed by the computer and software as it establishes the occurrence of T1, T2, and T3.

Calibration Sequence

As the participant's gaze is focused on the toy waver, his or her head is oriented toward the toy. Hence, the LRA elements that are being illuminated are expected to fall within a specific area, which is designated the rest gaze axis area of uncertainty (RGAAU). As the participant's gaze shifts to the loudspeaker and display, the head orientation will also shift, illuminating LRA elements that are within a stimulated gaze axis area of uncertainty (SGAAU). Owing to differences in each participant's muscular coordination, it may be necessary to recalibrate the test system with each new participant. A young participant with a poorly developed ability to hold his or her head still while gazing at an object would be expected to illuminate LRA elements over a relatively large area. On the other hand, an older participant with better muscular control might be expected to hold his or her head relatively still while looking at the object. In the case of the older participant, the area of illumination would be expected to be smaller than for a younger infant.

The beginning of the head turn event is established as the head begins to turn in the direction of the loudspeaker. This motion results in an LRA element being activated that is outside of the area within which all element activations indicate that the participant's head is oriented toward the toy waver. The reader's attention is invited to Figure 6. For purpose of clarity, the beginning of the head turn event (T2) would be established at the time when the red path moves outside of the green circle designating the RGAAU. The software would be written such that it detects the instant at which this occurs and stores the time of occurrence. The end of the head turn event (T3) is determined to occur at a time after T2 when all subsequent element activations occur within the SGAAU, the blue circle on Figure 6.

The borders of these areas of uncertainty must be precisely determined to determine with precision the times of occurrences of T2 and T3. As discussed above, the location and dimensions of these areas of uncertainty would be expected to be different from one participant to the next. Consequently, the test system would need to embody a calibration mode intended to determine the location and dimension of these areas of uncertainty before the test is conducted.

The calibration procedure would be executed by the test administrator before each test. A notional calibration procedure is as follows:

1. Participant takes his or her place within the test position with cap on and LPD energized.
2. Toy waver attracts the attention of the participant to invite attention to the initial position.
3. Position of the head as detected by array element illumination and presented on the control computer monitor is noted by the test administrator. (It is anticipated that multiple elements will be illuminated owing to lapses in muscle control creating inadvertent movements of the head, in spite of the fact that the focus of attention has not changed. The software modification making use of the map discussed above would give the test administrator the ability to place a circle around all element illuminations on the monitor by use of the mouse cursor. The child's gaze will focus on toy waver activity. The circle provided will declare the RGAAU. At the initiation of T1 during the actual test, the head will move outside of this circle as it begins its excursion to the new attention source. After T1, two subsequent element illuminations outside of this circle will be recognized by test software as T2 during the actual test.)
4. The test administrator initiates an audible event that invites the attention of the participant to the loudspeaker and display axis.
5. Repeat step 3. The circle provided as described above is declared to be the SGAAU. Two subsequent illuminations of elements within this circle during the test will be recognized by the software as T3.

Conclusions and Implications

As can be seen, the revision to the existing test provides the ability to measure the speed with which the participant is able to process the perception of an audible stimulus and convert it to a completed head turn response. For the concept to be valid, some measure of accuracy must be part of the measurement. This need for accuracy is predicated upon the idea that head position is an accurate indicator of focus of attention. This need not be assumed, since Caron, Butler, and Brooks [4] demonstrated the relationship at least in infants that have reached the age of 12 months. Parenthetically, the revision to the HTT might facilitate the measurements suggested by Caron et al. in younger infants. Since a connection has been established between certain pathologies and impairment of the head turn function [6], the measurement of these times can be a useful diagnostic tool for identifying conditions that impact such times, choosing therapies intended to remediate such conditions and longitudinally testing the success of those therapies when applied. The hereditary connection examined by other researchers [7] could also be further explored.

There is cross-sectional value in determining the impact of various environmental factors upon such measurements. It may be inferred that the interval T1 to T2 is useful in measuring mental processing time, while the interval T2 to T3 is an indicator of muscle control and optical/auditory performance. The impact of a wide array of factors upon these times could be tested.

This technique could be applied in the Freiberg and Crassini [8] examination of infant sensitivity to Sound Power Level (SPL). Minor adaptations that could be implemented by the tester are all that are required. The Hollich, Newman, and Jusczyk [9] inquiry into an infant's ability to synchronize visual and audible stimuli might enjoy a new dimension. The study conducted by Liu, Kuhl, and Tsoa [1] could be expanded to measure not only the basic response to the audible stimulus but the speed with which the response is executed. Additional potential applications of the test are numerous.

Potential Angular Accuracy

Angular accuracy is imparted by the number, position, and density of the elements in the LRA. The maximum number of elements will be established by the size of the footprint of the laser emission as it strikes the array and the size of the receptor elements. The LPD may be assumed to have a beam width that will not exceed 0.3 degrees, which is typical for the emitters used in such devices. It is anticipated that the distance from the head of the participant to the surface of the array should be on the order of 1–1.5 meters so that the array may be kept to a manageable size. At this distance, the footprint of the laser illumination is roughly 3–5 mm.

It is unlikely that orientation measurements will need to be accurate to less than one degree on either axis. More likely, 3–5-degree accuracy will be more than sufficient. At 1 meter away, the separation of receptor elements will need to be 52 mm to provide 3-degree resolution. It is further anticipated that the head position will need to be measured in a predominantly horizontal axis. As the participant turns his or her head from RGAAU to SGAAU, the head could be expected to traverse a horizontal arc described by 60 degrees. To permit the capture of element illumination produced as the head overshoots and then corrects, the array should go beyond the 60-degree arc by an additional 30 degrees in both directions. The total horizontal span of the array must therefore be 120 degrees. The array should also permit the capture of information as the head moves off axis in the vertical direction. This means that the array must permit element illumination 30 degrees above and below horizontal for a total vertical arc of 60 degrees. Given the 3-degree resolution requirement, such an array will contain 800 receptor elements. Higher element density provides additional accuracy in the angular measurement.

Considering the physical and optical parameters of the LPD and the individual receptor elements, it may be necessary to defocus the LPD to broaden the footprint. In this way, the likelihood that no element is illuminated by the LPD because of the wide space between receptor elements can be minimized.

Potential Time Accuracy

Time accuracy is a function of the parameters established in the subroutine that initiates the test and captures the position data from the LRA. Time accuracy resolution must be sufficient to capture the activation of each of the receptors as they are illuminated. Angular rotation of the head of the participant can be expected to be as high as 300 degrees per second for the time during which the head is in motion from its initial position to its new position. This means that a 60-degree movement can be executed in 200 milliseconds. It is unlikely that head motion in participants will exceed this rate. During that time, the LPD will have illuminated not less than 20 receptor elements. Therefore, test software must be able to capture 100 receptor activations per second. For this reason, a minimum of three digits to the right of the decimal point are needed to capture all receptor activation events.

Implementation of the Revision as a Research Initiative

The disciplines involved in this project include electronic engineering technology, computer engineering technology, software engineering, sociology, and medicine. As has been stated, the LRA must be constructed. Conceptually, this array makes use of a fairly simple photo transistor coupled to a binary number generator. Any undergraduate or graduate electronic engineering or technology program would contain the expertise to develop, construct, test, and produce this array. The LRA produces a binary number which represents the elements that have been activated by the LPD. This number is sent to the control computer and processed by the software that is resident in that computer. Again, an undergraduate computer engineering program would contain the expertise required to develop the interface between the LRA and the control computer. Development of the software might be the most complex task in the implementation of the system. This task may best be executed in a graduate-level software design program.

While the system design and implementation invokes technical or engineering disciplines, its employment is clearly within the disciplines of medicine or sociology. The graduate program at Washington University, in which the foundations of the concept were initially laid, can be observed as establishing the parameters of such programs.

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Biography

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