EFFECT OF OCULOMOTOR-AUDITORY FEEDBACK TRAINING ON PUTTING PERFORMANCE

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Abstract

This study investigated the effect of oculomotor-auditory feedback training on the stability of eye and head movements during the golf putting stroke and on putting performance. Twelve novice golfers participated in the study. Nine undertook training while three served as non-training controls. Initially, all subjects attempted 40 putts to a standard size golf-hole 9 feet away. Eye, head, and putter movements were recorded objectively using a wireless sensor system. The experimental subjects then used an oculomotor-auditory feedback regimen twice for 15 minutes each and attempted about 300 computer simulated trials. The 40 putts were then repeated for both groups. The data were analyzed for eye and head signals within the putting stroke time interval. The results showed a trend of better putting performance and reduced eye movements and head movements for the experimental subjects. The control subjects did not show these changes. This indicates that training using a simulator with oculomotor-auditory feedback improved eye and head stability during the golf putting stroke and enhanced putting accuracy. This also suggests that multi-sensory eye position error-based information can be combined at higher neural centers to enhance fixational oculomotor control.

Key Words

golf, infrared reflection eye sensor, objective electronic recording, oculomotor-auditory biofeedback, putting, simulator training, visual, wireless

INTRODUCTION

Multimodal input from visual, auditory, and tactile cues has been used to improve channel capacity for human-computer interface communication.[1-2] It has also been used in clinical applications such as chronic airflow obstruction[3] and rehabilitation in stroke patients.[4] Training in such interactive, multimodal environments has been shown to reduce symptoms and improve performance. For example, in subjects with chronic airflow limitation, multimodal endurance training was employed. Specific upper and lower limb exercises such as walking, stair climbing, arm ergometry, treadmill, and breathing alleviated exertional symptoms and improved ventilatory and peripheral muscle strength.[3] In stroke patients, training with augmented visual and auditory feedback helped to smooth movement trajectories and reduced undesirable compensatory trunk and shoulder movements.[4] Furthermore, multimodal training has been used with athletes. Various sensors were embedded in the equipment and on the athletes that allowed feedback to be provided via video analysis. This type of training has been applied in sports such as tennis and skiing to improve performance.[5,6]

Studies over the past several decades have demonstrated that most vision functions can be improved by specific laboratory-based vision training paradigms (see Ciuffreda and Wang[7] for a review). It was found that a full range of static and dynamic sensory/perceptual (e.g., visual acuity, steroacuity, etc.)[8-9] and motor (e.g., saccadic adaptation)[10] functions can be trained. The underlying processes for improvement in performance have been attributed to perceptual and motor learning.[7,11,12] The mechanism for perceptual learning is believed to involve a re-weighting of sensory channel input that leads to a bias in favor of the more relevant or specific task.[13] The mechanism for motor learning is believed to occur by increased synaptic efficiency similar to that in a Hebbian neural-network.[14]

Oculomotor feedback has been used in a variety of contexts to improve one's visual and motor abilities. For example, it has been used in conjunction with perceptual and motor training to enhance performance in a range of sports activities.[15]

Auditory feedback of eye movement position has been used to assist the control of eye fixation in the dark in normals[16] and in individuals with strabismus, amblyopia and nystagmus, in the light.[12,17,18]

Putting is a very important component of golf. It accounts for approximately 40% of the strokes taken during a round.[19] Although the act of putting appears to be simple, it is perhaps the most difficult part of the game.[20] The present study was undertaken to investigate whether accuracy of oculomotor fixation and head position, as well as putting performance, are improved following specific training using a putting simulator that provided visual feedback of eye fixation that was augmented by auditory feedback for larger eye deviations.

METHOD

Apparatus

Putting Experimental Measures

For the putting experiments, a wireless device was used for measuring head, eye, and putter movements objectively. It has been described in detail elsewhere.[21]

Figure. 1. Subject wearing visor with attached head sensor (mounted on the visor) and eye sensor (positioned in front of the eye).

Figure 2. Subject putting while wearing the device.

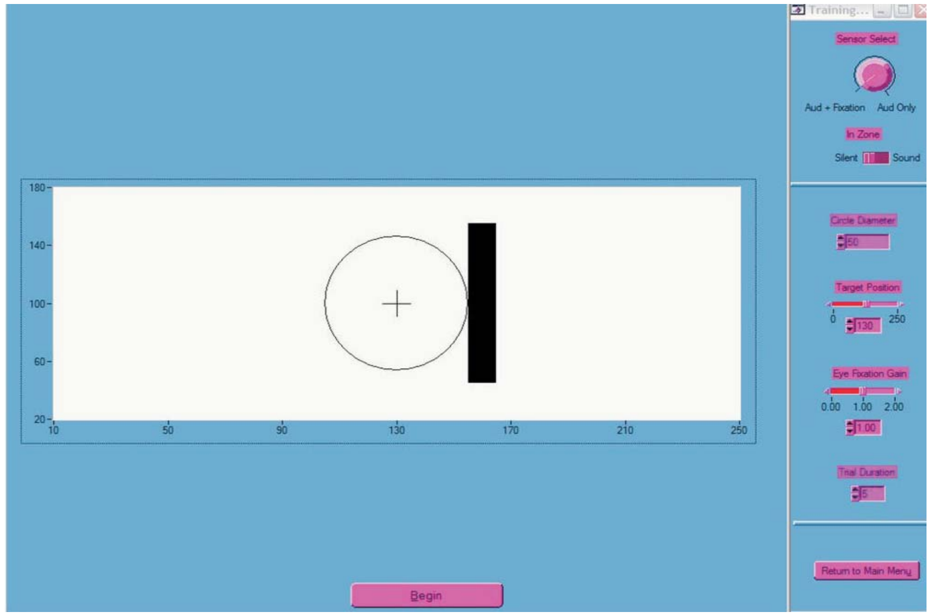

Figure 3. Display showing fixation target and simulated ball and putter blade. The lateral motion of the blade is controlled by a mouse. Following impact, the ball moves to the left at a speed that is proportional to the simulated putter blade speed. At right is the control panel for parameter selection.

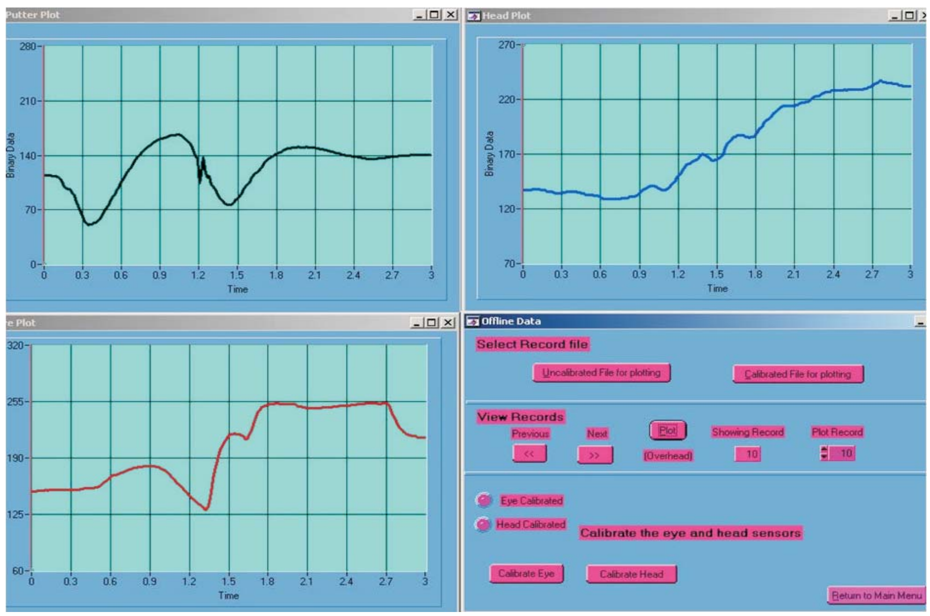

Figure 4a. Pre-Training. Typical record showing relatively large eye (lower left) and head (upper right) movements before ball impact (spike in putter movement trace, upper left). Upwards is in the direction towards the hole.

Briefly, it consisted of a circuit board containing an accelerometer that was mounted atop a visor worn by the subject. An infrared-reflection eye sensor, which was secured via a flexible cable to the side of the visor, was positioned in front the subject's left eye (Figures 1 and 2). The eye movement signal was sent via a ribbon cable to the circuit board atop the visor. Both the head acceleration and eye position signals were sent wirelessly via an onboard antenna to a receiving board connected to the Universal Serial Bus (USB) port of a laptop. A second circuit board containing an accelerometer was mounted on the shaft of a putter. The putter motion signal was sent wirelessly via an onboard antenna to the receiving board connected to the laptop. The location of the hole relative to the starting position of the ball remained the same for all trials. The subject practiced a few putts before the experiments to determine the direction and speed needed to make the putt. The subject was allowed to make any minor adjustments in direction and speed during these trials. The task was to execute the putting stroke. The movements of the eye, head, and putter are mostly in a plane containing the eyes, ball and hole. Thus, the movements that are measured are mainly in the lateral direction towards (or away from) the hole.

Training Device

The perceptual and motor putter training device consisted of a computer screen (22° horizontal x 17° vertical) that displayed a black circular target (3.7° dia.) with a center cross (0.7° x 0.7°) and a vertical black rectangular bar (0.7° horizontal x 4.5° vertical) that represented a simulated putter blade (Figure 3). The subject sat approximately 70 cm from the screen and wore the same visor that was used in the baseline putting measures. The fixational eye response was displayed as a red dot (0.7° dia.) on the screen. The subject's task was to keep the red dot (fixation point) in contact with the cross and to

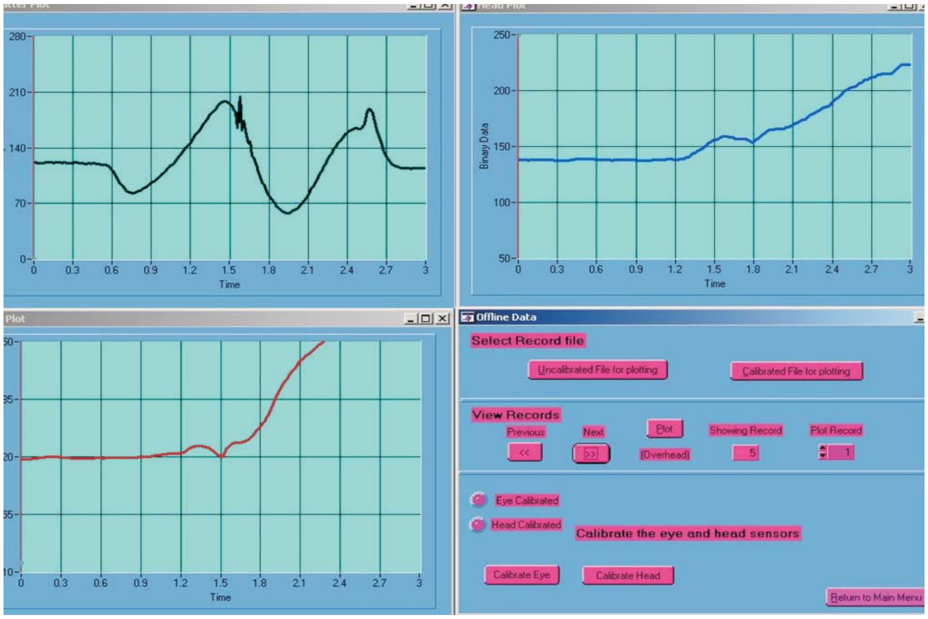

Figure 4b. Post-Training. Typical record showing relatively small eye (lower left) and head movements (upper right) before ball impact.

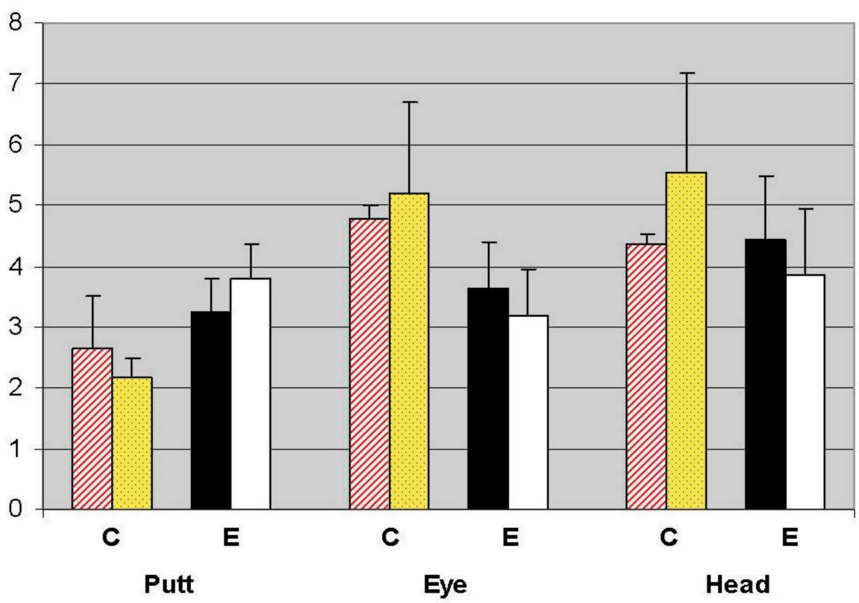

Figure 5. Putting performance [Putt (percentage made, divided by 10)], and eye [Eye] and head [Head] variation (RMS, cm), under the conditions of: Control (C) – Session 1 (striped) and Session 2 (dotted); and Experiment (E) - Pre- (black) and Post- (white) Training. Mean ± 1 standard error of the mean.

TABLE 1.
Averaged performance across subjects for Control Group (n=3) and Pre- and Post-Training Group (n=9).

	Control		Experiment	
	Session 1	Session 2	Pre-Training	Post-Training
Putt (% made)	26.3 (8.6)	21.7 (3.1)	32.4 (5.6)*	37.9 (5.7)*
Eye (RMS, cm)	4.80 (0.22)	5.20 (1.50)	3.63 (0.78)*	3.20 (0.74)*
Head (RMS, cm)	4.36 (0.18)	5.56 (1.61)	4.44 (1.05)	3.20 (0.74)*

**Shows a statistical trend in the difference between Pre- and Post Training (p < 0.1). For all other differences, p > 0.1. Standard error of measure values are the shown in parentheses. RMS=root mean square*

execute the simulated putting stroke when the red dot was touching the cross for a short, but stable, period of time. A tone was generated if the eye position was outside the circle. Lateral motions of a computer mouse were used to control movement of the simulated putter blade on the computer screen. This motor movement of the mouse was meant to simulate the lateral motion of the hand and arm during the actual golf putting stroke. When the simulated putter face contacted the circle on the screen, a large red circle (3.7° dia.) appeared and moved horizontally to the left, thereby simulating the rolling of a golf ball. The speed of ball movement was directly related to the speed of the simulated putting stroke.

A. Pre- and Post-training Putting Session

Twelve novice golfers (10 males and two females) ranging in age from 20-24 years participated in the study. Nine of these subjects served as experimental subjects, while three served as controls (i.e., without training). On the first day of the experiment, the subject attempted to execute, without prior instructions, 40 putts to a standard size golf-hole located 9 feet away. For each attempted putt, the eye, head, and putter movements were recorded over a 3-sec epoch using the wireless sensor system. Also recorded was the putting accuracy (i.e., whether the putt was made or missed). Following the oculomotor-auditory training (see below), this procedure was repeated on a subsequent day.

Prior to participation in the experiments, all subjects provided written informed consent. The study was approved the Rutgers University Institutional Review Board committee.

B. Simulator-Based Oculomotor-Auditory Feedback Training

The perceptual and motor putter training was performed immediately after the Pre-Training putting task on the first day, as well as just before the Post-Training putting task on a subsequent day. The subject's task was to fixate the center cross and execute a simulated putting stroke using the mouse, while attempting to maintain eye fixation within the black target circle. Following the simulated stroke using the mouse, the red dot, which represented the putted ball, moved to the left on the screen and eventually off the screen. The original black circle with the cross remained on the screen to provide a fixed reference. This was repeated at a rate of about 25 strokes per minute over a 15-minute period. Occasionally, the training was interrupted for eye sensor adjustment or fatigue. The total number of training trials was approximately 300.

C. Control Sessions 1 and 2

The control subjects (two males, one female) performed the same putting tasks as the experimental subjects, except they did not receive oculomotor-auditory feedback simulator training. These were designated as Control Sessions 1 and 2 corresponding to the Pre- and Post-Training sessions.

D. Data Analysis

The eye, head, and putter data were converted via calibration to equivalent displacement (in cm) on the putting surface. For each record, the beginning and end (i.e., at the moment of ball impact) of the putter motion were delimited manually, and the root mean square (RMS) of eye and head movements within this interval was calculated. The subject's average RMS value was obtained for each of the two experimental sessions. Then, a t-test was performed between the Pre- and Post-Training sessions for the eye and head RMS values across all subjects. A similar analysis was performed for the control subjects to assess the difference in RMS values between Control Sessions 1 and 2.

RESULTS

Typical records during the putting stroke are presented for Pre- (Figure 4a) and Post-Training (Figure 4b). In the putter trace (upper left), the beginning of the backstroke is seen as a downward movement in the trace (upwards is towards the hole). The point of impact is at the sharp spike. Since the trace is derived from acceleration data, it provides the times of stroke initiation and impact, but not the exact position of the putter during its time course. The eye and head movement traces are shown in the lower left and upper right plots, respectively. Comparison of the Pre- (Figure 4a) and Post-Training (Figure 4b) traces from the time between initiation of the backstroke and prior to ball impact shows that the eye and head movements exhibit less variation following the training.

Figure 5 shows a bar graph of results for control (C) and experimental (E) subjects. For the control subjects, the percentage of putts made was lower for Session 2 than Session 1. For the experimental subjects, it was greater following oculomotor-auditory training. Also presented is a comparison of the RMS values of eye and head movement measured from the beginning of the backstroke to the point of ball impact. (Table 1.) The control subjects exhibited a trend of increased RMS for eye and head movements from Session 1 to Session 2. On the other hand, the experimental subjects show a trend of decreased RMS for eye and head movements following oculomotor auditory training. Table 1 summarizes the parameter values for the control and experimental subjects.

DISCUSSION

Biofeedback refers to the process of gaining voluntary control over a bodily function by immediate use of specific information regarding its physiological state. Thus, the individual is provided information from biological processes normally beyond their awareness. This then facilitates the regulation of these same functions.[18] More specifically, oculomotor-auditory feedback refers to the use of visual and auditory signals related to and correlated with changes in eye position. These signals can be used to monitor one's oculomotor status, such as the fixational eye movement system and its saccadic and drift-related errors as per the present study. Over a relatively short time period, the subject learns to use this information to enhance oculomotor performance. It is presumed that this skill transfers to improved task performance, as found in the present study with respect to putting. This is consistent with earlier studies involving multi-sensory feedback training/therapy in a variety of normal and abnormal visual conditions.[12, 22]

Training in an interactive, multimodal environment has been shown to improve performance in patients with disabilities[3,4] and in athletes.[5-6] Our study examined a specific application of multimodal training, namely one that used computer display to provide eye position information. A criterion was to remain within a circular region that would elicit a tone if the eye excursion moved beyond the circle. The computer mouse was not intended to be a substitute for the putter. It was used to provide an overall movement pattern that mimicked the back and forth motion of the putting stroke.[23] Nevertheless, the improvement in performance following simulator training found in our study provided support for the use of this multimodal feedback technique to improve hand motion and to train the eye and head to remain steady during the putting stroke.

Putting is arguably the most difficult part of the golf game and accounts for about 40% of the score.[18,19] Even a small improvement in putting performance of about 5%, as found in this study, can be the difference between a poor and an average score, or between an average and a good score. We speculate that the lesson learned by the subjects includes not only the oculomotor-auditory feedback training regimen, but also the information provided by the replay of the time courses of their eye and head motions. That is, they can visualize for the first time what their eyes and head are actually doing during the putting stroke. This may confirm or perhaps even contradict their subjective notion of their oculomotor responses. Nevertheless, these displays provide the potential for correction of forward anticipatory movements or inappropriate tracking of the putter's to-and-fro motion. This, in turn, could help to further improve performance. Overall, it is hoped that oculomotor-auditory training, which emphasizes steady eye and head position while executing putting motions, can be translated into improved eye-hand coordination and enhanced performance on the golf course.

CONCLUSION

This study demonstrated the effectiveness of multimodal simulator training using oculomotor-auditory feedback in improving putting performance. The computer mouse movement was not intended to be a substitute for the normal putting stroke, but rather was used to mimic its back and forth motion along the line of the putt. Nevertheless, visual-motor training appears to improve hand motion, as well as eye and head stability, during the putting stroke. This is shown by the continued improvement in percentage of putts made, and the reduction in eye and head movements, following simulator training. In contrast, control subjects without oculomotor-auditory feedback training did not show improvement in either putting performance or eye and head stability.

References

1. Flanagan JL, Marsic I, Medl A, Burdea G, et al. Multimodal human/machine communication. In: De Natale F, Pupolin S, eds. Multimedia Communications. London: Springer-Verlag, 1999:502-9.
2. Corradini A, Mehta M, Bernsen N-O, Martin J-C, et al. Multimodal input fusion in human-computer interaction on the example of the NICE project. Proc. NATO-ASI Conference on Data Fusion for Situation Monitoring, Incident Detection, Alert and Response Management, Yerevan, Armenia, 2003:1-15.
3. O'Donnell DE, McGuire M, Samis L, Webb KA. General exercise training improves ventilatory and peripheral muscle strength and endurance in chronic airflow limitation. Am J Respiratory and Critical Care Med 1998;157:1487-97.
4. Huang H, Ingalls T, Olson L, Ganley K, et al. Interactive multimodal biofeedback for task-oriented neural rehabilitation. Proc. IEEE Engin. in Med. and Biol. 27th Annual Conference, Shanghai, China, Sept., 2005:2547-50.
5. Hey J, Carter S., Pervasive computing in sports training. IEEE Pervasive Computing 2005;4:54.
6. Michahelles F, Schiele B. Sensing and monitoring professional skiers. Pervasive Computing 2005;4:40-6.
7. Ciuffreda KJ, Wang B. Vision training and sports. In: Hung GK, Ciuffreda KJ, eds. Biomedical Engineering Principles in Sports. New York: Kluwer Academic/Plenum Publishers, 2004:407-26.
8. Goldstone RL. Perceptual learning. Ann Rev Psychol 1998;49:585-612.
9. Rosenbaum DA, Carlson RA, Gilmore RO. Acquisition of intellectual and perceptual-motor skills. Ann Rev Psychol 2001;52:453-70.
10. Semmlow JL, Gauthier GM, Vercher JL. Mechanisms of short-term saccadic adaptation. J. Exp Psychol Hum Percept Perform 1989;15:249-58.
11. Abernethy B. Enhancing sports performance through clinical and experimental optometry. Clin Exp Optom 1986;69:189-96.
12. Ciuffreda KJ, Tannen B, Rutner D. Multi-sensory feedback therapy for oculomotor dysfunction. In: Hung GK, Ciuffreda KJ, eds. Models of the Visual System. New York: Kluwer Academic/Plenum Publishers, 2002:741-69.
13. Dosher BA, Lu Z-L. Mechanisms of perceptual learning. Vis Res 1999;39:3197-221.
14. Lisberger SG. The neural basis for learning of simple motor skills. Sci 1988;242:728-35.
15. Wilson TA, Falkel J. Sports Vision: Training for Better Performance. Leeds, UK: Human Kinetics Europe Ltd., 2004.
16. Hung GK, Ciuffreda KJ, Carley CA, Fang P, et al. Auditory biofeedback to control vertical and horizontal eye movements in the dark. Invest Ophthalmol Vis Sci 1988;29:1860-5.
17. Smith WM, Control of eye fixation by auditory biofeedback. Psychonomic Sci 1964:233.
18. Ciuffreda KJ, Goldrich SG. Oculomotor biofeedback therapy. Int Rehab Med 1983;5:111-7.
19. Pelz D, Mastroni N. Putt Like the Pros. New York: HarperCollins, 1989:3.
20. DeGunther R. The Art and Science of Putting. Chicago: Masters Press, 1996:7-10.
21. Hung GK, Ciuffreda KJ. Effect of wearing single-vision & progressive lenses on eye & head movements during the golf putting stroke. J Behav Optom 2006;17:115-9.
22. Ciuffreda KJ. The scientific basis for and efficacy of optometric vision therapy in nonstrabismic accommodative and vergence disorders. Optometry 2002;73:735-62.
23. Nicklaus J, with Bowden K. Golf My Way. New York; Simon and Schuster, 1974.

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