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ORIGINAL ARTICLE

The effect of stroboscopic visual training on eye–hand coordination

Paul Ellison[1] · Chris Jones[1] · S. Andy Sparks[1] · Philip N. Murphy[2] · Richard M. Page[1] · Evelyn Carnegie[1] · David C. Marchant[1]

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Abstract

Background Stroboscopic visual training (SVT) has been shown to improve cognitive skills and perceptual performance by carrying out events under situations of intermittent vision.

Aims The aim of this study was to investigate whether an SVT training period could improve the eye–hand coordination (EHC) performance on a practiced task for a group of sports participants.

Methods Sixty-two male participants were randomly assigned to either a strobe group (SG $n = 31$), or control group (CG $n = 31$). The method employed a Sport Vision Trainer™ 80 sensor pad to measure the mean speed of reaction time of participants extinguishing randomly illuminated lights on an electronic board. One trial consists of 20 lights. One week following pre-testing on the Sport Vision Trainer™ (4 × 6 trials), a pre-training baseline assessment of 1 × 6 trials was conducted to measure their abilities to complete the EHC task. Four × six trials (480 lights) were then completed in the training phase with the CG continuing to train with unimpaired vision, whilst the SG wore Nike Vapor Strobe® (controlled rate of 100 ms visible to 150 ms opaque). Post-training assessments were administered immediately, 10 min and 10 days after SVT each consisting of six trials (120 lights). A visual search (VS) non-trained transfer test was also administered pre-SVT and after 10 days. This involved an e-prime programme using a laptop where participants had to identify a target stimulus located amongst distractor stimuli.

Results Treatment effects were observed at each time point. Baseline performance was significantly related to retention performance immediately ($p = .003$), 10-min post ($p = .001$) and 10 days post-training ($p = .002$). No significant differences were found for the VS test.

Conclusion An acute SVT exposure using stroboscopic goggles significantly improved EHC performance. Future research should explore these mechanisms further using different exposure, frequencies, and focused identification of training drills as a complementary intervention for individual or team sports.

Keywords Stroboscopic visual training · Sport vision training · Nike Vapor Strobe · Skill acquisition

Introduction

There is a growing body of research investigating improvement in sport performance as a result of the use of vision training interventions [1–3]. Perceptual information influences many motor tasks, subsequently enabling accurate control to be maintained in fluctuating or uncertain environments [4]. Consequently, alterations to the environment will regularly produce task performance variations. As vision is typically our central source of sensory information, researchers have established different methods to explore visuo-perceptual mechanisms (see Williams and Jackson [5] for a review). For example, research has been conducted to explore the possible uses of audio-based interventions to promote significant improvement in sport performance [6]. Alternatively, the use of synchronised metronome training and temporally occluded videos has been shown to be successful in improving elite performers timing ability and anticipation in female soccer players and male goalkeepers, respectively [7, 8].

✉ Paul Ellison
paul.ellison@edgehill.ac.uk

1 Department of Sport and Physical Activity, Edge Hill University, Ormskirk, England L39 4QP, UK

2 Department of Psychology, Edge Hill University, Ormskirk, England L39 4QP, UK

A common experimental intervention has been to present participants with discontinuous visual feedback or information while they complete tasks demanding a high amount of temporal and spatial precision (visual occlusion) [9]. This procedure involves using video editing to occlude body parts or movements to investigate how athletes use vision to anticipate actions successfully. Early studies indicated that visual pick up might not be essential for continuous motor control due to continuous interaction of motor processes with cognitive and perceptual processes [10–12].

However, in tasks that encompass interceptive action, research has reported that the comparative prominence of vision is magnified [13]. Consequently, authors have suggested that the neural reaction of the visual system is united which effectively results in uninterrupted perception [14, 15]. Through practice and enhanced knowledge due to experience, accomplished performers have more efficient and optimal cognitive processes making fewer errors by means of advanced visual cues to predict the result [16, 17]. More recently, technological advances have led to stroboscopic spectacles being developed, which, have been shown to reduce this dependence and force the performer's visual system to train in more difficult conditions, potentially leading to improved performance once the eyewear has been removed [1, 18].

The growth of liquid crystal occluding spectacles (stroboscopic) has delivered a potential technique of addressing some of the restrictions intrinsic to past research which include field accessibility, portability and ease of administering interventions [1]. The underpinning theory of stroboscopic vision training (SVT) is that the reduction in visual samples received forces the participant to employ the remaining samples more resourcefully and make greater use of other senses, in particular, kinaesthetic awareness. By taking away partial vision, varying speeds and modes, another principle of stroboscopic vision is to assist in creating autonomous schemas to prepare an athlete for performance. This reduction in visual samples received has been assumed to improve the natural connection between visual perception and action mechanisms and improve skills in anticipation [19] and processing speed [20]. For a comprehensive review, see Wilkins and Appelbaum [1].

Stroboscopic visual training has been shown to have an impact on selected visual variables (e.g. peripheral accuracy), and provides an opportunity to examine eye–hand coordination (EHC) in relation to performance evaluation due to a paucity of research in this area. Research using stroboscopic exposure has been conducted into the prevention of air travel sickness [21], space motion sickness [22], and has been shown to be an effective countermeasure in these particular ecologically valid environmental settings.

The question of whether visual-motor training under stroboscopic visual conditions produces and generalises learning to an untrained domain is currently under debate [1, 2]. The logical progression is to examine the integration of discontinuous visual samples in several perceptual-motor activities. In tasks that are less reliant on uninterrupted visual parameters (e.g. movement behaviour), there are often no effects of discontinuous vision manipulations, even with obscured vision intervals as long as 500 ms [23]. When the binocular samples are disconnected by a non-visual interlude of less than 40–80 ms, performance is maintained at a practical level [24]. This area of research has examined the integration of discontinuous visual samples in perceptual-motor tasks such as manual aiming and one-handed catching. For example, an analogous decrement in catching performance has been identified for increase in the no-vision interval between uninterrupted 20 ms visual samples (i.e. from 0 to 80 ms) [4].

Recent research has investigated the use of SVT to improve sporting performance [2, 18–20, 25–32]. Overall, these studies have utilised differing training period lengths and time points for measurements of performance. For example, Appelbaum et al. [25] conducted research on 157 university students and athletes exploring catching, frisbee throwing accuracy, and speed and agility drills. The participants attended between 2 and 10 sessions of varying lengths of time (15–28 min). Strobe Vision Training led to significantly improved detection of centrally presented motion coherence and improved divided attention, but not in multiple-object tracking. Applebaum et al. [26] followed a similar design and demonstrated that an SVT group showed greater improvement in memory, and was also retained 24-h post-training period. At present, few studies employ post-training tests to measure any residual learning. An exception to this is Smith and Mitroff's research [19] that assessed anticipatory timing (AT) using a 5–7 min acute exposure to SVT and included immediate, 10-min and 10-day post-training period performance tests. These authors indicated that the experimental group had significantly better anticipation in post-test but not in retention.

Reichow et al. [27] also evaluated stroboscopic effects on AT using a Bassin Anticipation Timer. Stroboscopic vision training did not improve accuracy in this case and the authors speculated that this might be due in part to the relatively slow testing speeds used. An investigation by Schwab and Memmert [3] used impulse shutter glasses as part of a 6-week general vision training (GVT) intervention with youth male field hockey players. Although they found improvement in terms of performance for the experimental group, the strobes were one of a multitude of loading devices and therefore effects could not be attributed exclusively to the effects of the SVT.

An intervention study combining multiple weeks of prolonged exposure to SVT drills in conjunction with typical softball activities identified that effects of training may have led to improvement in sensorimotor skills [28] The collegiate athletes completing a SVT exhibited improvement in dynamic drills associated with sensory-motor performance that are important for sporting performance. Second, a 6-week pre-season period (followed by a maintenance programme during the season) including standard vision training exercises (including wearing strobes) was found to improve bating parameters by 10% or more in a group of university baseball players [29]. Whilst it is impossible to know if the stroboscopic element was the primary cause for improvement, this seemed encouraging. There is also currently a pre-registered study combining SVT with other techniques whilst testing far transfer to baseball performances and using a placebo-controlled design which may add extra understanding of the techniques used in an applied setting [31].

Wilkins and Gray [20] investigated the acquisition of ball catching skills over a sustained 6-week period. No significant differences were found between catching or visual tests, however, catching performance changes were strongly correlated with scores in the visual tests. Another SVT intervention exposed male national hockey league players to either strobe or control conditions during their normal training camp activities [24]. The strobe group wore glasses a minimum of 10 min a day for 16 days and were observed to show 18% improvement post-training on the ice hockey-specific performance tasks. Consequently, stroboscopic spectacle equipment offers a flexible and reasonably unobtrusive solution to investigating perception and action in its natural occurrence; however, less is understood with regard to more acute exposures.

Temporal and spatial paradigms only capture a specific aspect of the task and omit a real-world response. This type of research typically shows that experts are better able to envisage event outcomes using information offered early in the event structure [33]. This phenomenon has been investigated in terms of the overall effect of perceptual cue usage and visual search behaviours on performance [34]. Studies using this type of technology suggest the use of natural tasks may help discover expertise effects in a performance setting, away from traditional laboratory settings [33, 35, 36]. Research testing stroboscopic exposure to date has suggested potential influences on a variety of perceptual or cognitive abilities [26]. One way to train vision and attention for sport is to practice and train in suboptimal environments to overload perceptual processes, making return to the performance setting seem easier [19]. Other training regimes already apply this principle, for example, the use of resisted sprint training to improve speed and strength performance [37].

From a skill acquisition perspective, early research by Bennett, Button, Kingsbury and Davids [38] suggested that varying visual informational constrictions to encourage investigative rehearsal might signify an important instructional methodology to motor learning in a sporting environment. The present study employs some of the same logic and does so through the use of intermittent SVT. Under normal circumstances, we use continuous online information from vision, offering intermittent snapshots of the visual world forces performers to perform in these suboptimal conditions. In a more recent study, Wilkins, Nelson and Tweddle [30] conducted pilot study research with three elite youth football goalkeepers to determine if a longer prolonged exposure (10 h over a 7-week period) SVT protocol might have the potential to improve visual responses. Whilst findings suggested potential of improving visual response times, evidence for benefits for a range of other perceptual and visual skills including EHC was not found. It would therefore be useful investigate whether a shorter/acute SVT period has a similar effect on EHC.

Aims and hypothesis

The primary aim of the present study was to determine the effects of an acute training period of SVT on the practiced task (measured by three retention tests: immediately, 10 min, and 10 days later). We used a Sport Vision Trainer™ that measures reaction time and eye–hand coordination ability requiring the simultaneous use of hands and eyes as the main test and practice mechanism for the study [39]. The secondary aim was to establish if these benefits transfer to a non-trained visual search (VS) task that relies on different (but similar) cognitive mechanisms measuring speed and accuracy.

Based on previous research, it was hypothesised that participants completing SVT would significantly improve performance in the retention tests, whilst the control participants would have some improvement (due to task familiarisation), however, not of the same magnitude.

Methods

Participants

Following informed consent and institutional ethics approval, sixty-two male sports participants took part in the study. The sample size selected was identified using an a priori calculation from pilot study data. This was identified as being sufficient to provide appropriate statistical power (0.8; $p \leq .05$) to evaluate the main effects for the primary outcome measure. The participants were of mixed abilities ranging from collegiate to national standard in a variety of team and individual sports. Enrolled participants were randomly assigned to either a strobe group (SG; $n = 31$, age 20.82 ± 1.54 yrs.), or control group (CG; $n = 31$, age 21.34 ± 4.27 yrs.). Records of the years' experience of competing in their sport (SG 6.84 ± 4.36 yrs. CG 7.34 ± 3.98 yrs.), and hours of training per week (SG 5.83 ± 3.48 h, CG 5.86 ± 3.41 h) were obtained. One participant was excluded due to suffering from epilepsy and all were novice to the EHC task.

Research design

The study was conducted as a between-groups (SG × CG) repeated-measures design whereby participants undertook EHC testing at five measurement points: pre-testing, baseline (pre-training), immediately post-training, 10-min post-training, and following a 10-day retention period. Participants completed 6 × trials of 20 lights (120 lights in total) at all of these time points, taking approximately one and a half minutes, with the first two trials at each acting as a familiarisation and being expunged from the data analysis. The device used for testing and training of EHC was the Sport Vision Trainer™ 80 sensor board (Sports Vision Pty Ltd, Australia) which has been proven to be reliable [39]. The same experimenter administered all the pre- and post-tests plus the SVT training programme. The SG performed an acute SVT training session of six trials of twenty light random stimuli, four times (24 trials of 20 lights = 480 lights) directly after the baseline test whilst wearing strobe glasses, whereas the CG performed the same training protocol with unimpaired vision.

To help to control for baseline differences, the primary outcome measures were calculated as the differences from pre-training to each of the subsequent post-training measures (immediate, 10 min and 10 days) in EHC performance. A secondary outcome measure included a non-trained VS transfer test.

Optometric tests

General optometric tests for static visual acuity, dominant eye and colour vision were administered prior to testing to establish the level of participants' eye care and assess suitability for the study. The tests were identified as broadly representative of the assessment techniques used by practicing sport optometrists and took approximately 10 min to administer.

Stroboscopic training

The SG were seated for 5 min and habituated wearing the Nike Vapor stroboscopic eyewear® (Nike Inc, Baeverton, USA). Intervention studies tend not have any habituation period prior to testing, however, to minimise risk of potential seizures due to any previously undiagnosed photosensitivity of participants a short period of orientation was conducted. Participants were seated and asked to stand for 15 s after each 1-min interval to habituate their visual system with the strobes and the environment. The spectacles have liquid crystal in the lenses that alternate from transparent to opaque states. The transparent state shows complete visibility and the opaque state shows a grey shade of higher visual difficulty. The rate of alternation between transparent to opaque is controlled by selecting the required speed (8 levels). For the present study, they were set to level 3, 100 ms clear, 150 ms opaque to reproduce the same frequency level utilised in previous research [19]. Practice took approximately 7–8 min depending on individual performances to reproduce a similar exposure to SVT in previous research [19]. The CG sat for 5 min prior to testing without the eyewear. A pre-testing measurement consisting of 4 × 6 trials was conducted 1 week prior to the training session. A wall-mounted non-portable Sport Vision Trainer™ 80-sensor pad (1.25 m × 1.25 m) (weight 15 kg) was used for the EHC testing protocol (Fig. 1).

A self-paced 20 target light protocol set to a random sequence was initiated. Participants were required to touch each light as it was illuminated on the Sport Vision Trainer™ as quickly as possible. The faster a light was hit the faster the next light was presented. Time to hit a sequence of 20 lights was recorded. The mean time for all 20 lights to be extinguished in a trial was recorded for analysis. The Sport Vision Trainer™ programme randomised the target order and location for every trial to ensure fair test comparisons between users. The first two trials of 20 lights were classed as practice runs and the means of the last four measurement trials were displayed at the end of each one. The training session consisted of undertaking six trials of twenty light random stimuli, four times (i.e. a total of 480 lights). The CG also completed the same amount of trials (without the eyewear). The participants all completed retention tests on the Sport Vision Trainer™ consisting of random sequences of 6 × 20 lights, immediately post-training, 10 min post and 10 days post (i.e. a total of 120 lights at each retention point). The 10-day test took place at the same time of day to avoid any effects of circadian variations [40, 41]. The first two

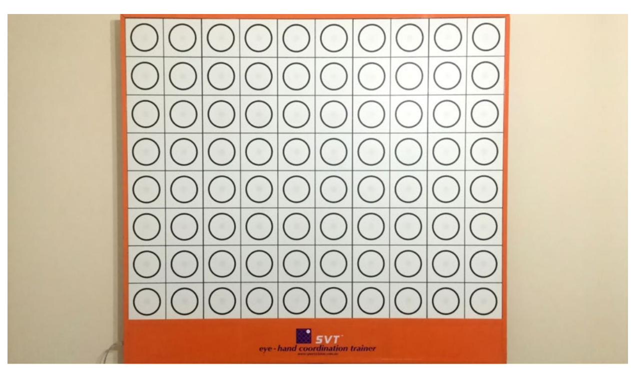

Fig. 1 80 light sports vision trainer (SVT™)

measurement runs were again discarded, and a mean of the final four taken for analysis.

Visual search (non-trained transfer task)

Visual search effectiveness was assessed (pre-training and at the 10-day data collection point) using a laptop with a computer programme (e-Prime 2.0, Psychology Software Tools Inc, USA). We presented a task used in previous research [42], allowing analysis of data pertaining to VS speed (ms) and VS accuracy (%). Participants pressed the space bar to initiate a practice block of 24 trials followed by 4 subsequent blocks of 24 trials each for analysis. Each search display (trial) contained 12 items (1 target and 11 distractors). The target was a T stimulus rotated 90° to the right or left and participants pressed one of two keys (x = left, m = right) corresponding to whether the top of the T was pointing to the right or left. The distractor stimuli were L shapes presented randomly in one of four orientations (0°, 90°, 180°, or 270°) (Fig. 2).

Spatial configurations used in practice were not used in experimental condition to avoid any recognition of previous examples. Instructions were both verbalised by the experimenter and on-screen prompts reminded participants of procedure in between blocks to allow for short rest periods. It was stressed that participants should respond as quickly and accurately as possible. Tests took approximately between 2.5 and 3 min depending on the participant [42]).

Data analysis

A post hoc power analysis was completed using G*Power software (v.3.1, Heinrich-Heine-Universistat, Dusseldorf, Germany), with the statistical analyses performed using the primary and outcome measures. The partial eta squared values generated for the between-group differences retention test measures were used to generate effect size f values to subsequently calculate statistical power. Post hoc power analyses identified that the current sample size (n = 62) elicited an observed statistical power of > 0.868 for the pre to training time, pre to immediately post, pre to 10-min post, and pre to 10-day post differences of the primary outcome measure (EHC).

Prior to parametric analyses, the stacked standardised residuals were visually and statistically checked for normality q–q plots and a Kolmogorov–Smirnov test (p > .05). Mauchly's test of sphericity was performed for the dependant variables, with a Greenhouse–Geisser correction included if test significance was indicated. Due to between-group baseline differences, the treatment effect differences (baseline to each of the post-trial measurements) were used for statistical analyses, with separate analysis of covariance (ANCOVA) being utilised to examine differences in the performance between the two groups (SG and CG) over the training period (immediately post, 10-min post, 10-day post). The baseline measures were utilised as a covariate [43]. Where significant main effects or interactions were observed, post hoc pairwise comparisons with a Bonferroni correction factor were applied, with 95% confidence intervals for differences (CI diff) also reported. All statistical analyses were completed using PASW Statistics Editor 25.0 for Windows (SPSS Inc, Chicago, USA), with statistical significance set at $p \leq 0.05$. Mean performance scores are presented descriptively as absolute values to provide context of any training effect, with data reported as mean ± standard deviation. For the statistical analysis associated with the ANCOVA, data are reported as estimated marginal means (and associated 95% CI) for within-group changes that are adjusted for the covariate of baseline performance, and mean differences for the between-group differences.

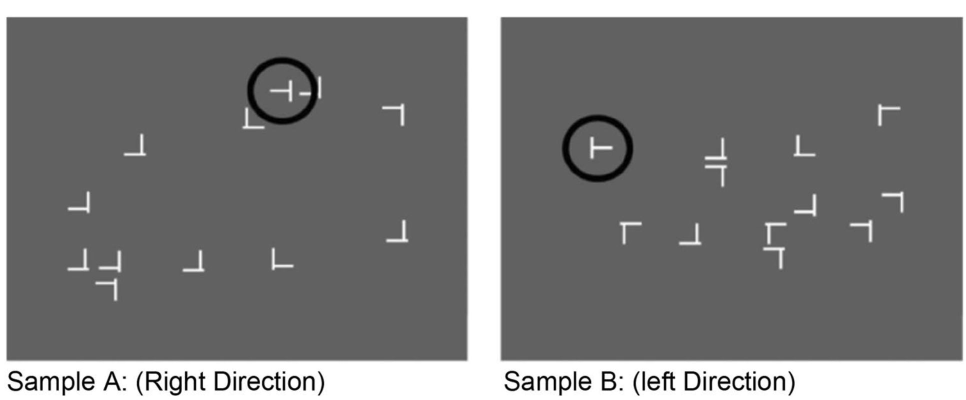

Fig. 2 Screenshots of non-trained visual search transfer task

Results

Descriptive analyses

Mean performance scores are presented descriptively to provide context of the training effect (Table 1).

Table 1 Descriptive performance data. Data are presented as mean ± SD

Measurement point	EHC (s)	VS accuracy (%)	VS speed (ms)
SG (n = 31)			
Baseline	9.59 ± 1.29	92 ± 3	936 ± 156
Training	10.33 ± 1.17		
Immediately	9.01 ± 1.25		
10 min	8.51 ± 0.94		
10 days	8.47 ± 0.86	91 ± 3	819 ± 117
CG (n = 31)			
Baseline	9.09 ± 0.94	91 ± 4	941 ± 152
Training	8.88 ± 1.00		
Immediately	8.97 ± 1.16		
10 min	8.58 ± 0.95		
10 days	8.47 ± 0.95	90 ± 5	849 ± 121

Statistical analyses

Primary outcome measures

A significant difference during the training period between the two groups was observed ($F_{(2,62)} = 48.172$, $p = .001$), with the SG eliciting a reduction in completion times from baseline whereas the CG elicited an improvement in completion times (Table 2). For the immediately post ($F_{(2,62)} = 9.793$, $p = .003$), 10 min post ($F_{(2,62)} = 12.069$, $p = .001$) and 10-day post-training periods ($F_{(2,62)} = 10.908$, $p = .002$), the SG elicited significant improvement in performance when compared to the CG.

Secondary outcome measures

There were no significant differences for the changes in performance of VS time ($F_{(1,59)} = 2.007$, $p = .162$) at the 10-day post-training between the SG and CG. A similar response was observed for changes in performance of VS accuracy ($F_{(1,59)} = 1.296$, $p = .260$) with no significant differences observed between groups.

Table 2 Estimated marginal means of the within-group changes for the primary and secondary outcome measures

Variable	Primary outcome measures		Secondary outcome measures	
	Measurement point	EHC (sec)	VS accuracy (%)	VS speed (ms)
SG (n = 31)				
Within-group changes from baseline (95% CI)[b]	Training	0.777 (0.570 to 0.985)		
	Immediately post	− 0.874 (− 1.174 to − 0.573)		
	10 min	− 1.308 (− 1.568 to − 1.049)		
	10 days	− 1.339 (− 1.5721 to − 1.107)	− 0.706 (− 0.707 to − 0.705)	− 117.358 to (− 143.958 to − 90.759)
CG (n = 31)				
Within-group changes from baseline (95% CI)[b]	Training	− 0.253 (− 0.461 to − 0.046)		
	Immediately post	− 0.201 (− 0.501 to − 0.100)		
	10 min	− 0.663 (− 0.922 to − 0.403)		
	10 days	− 0.790 (− 1.022 to − 0.557)	− 0.705 (− 0.706 to − 0.705)	− 90.726 (− 117.325 to − 64.126)
Mean differences between groups (95% CI for differences)	Training	1.030 (0.733 to 1.328)[a]		
	Immediately post	− 0.673 (− 1.104 to − 0.243)[a]		
	10 min	− 0.645 (− 1.017 to − 0.274)[a]		
	10 days	− 0.550 (− 0.883 to − 0.217)[a]	− 0.001 (− 0.002 to − 0.000)	− 26.63 (− 64.25 to − 10.99)

Mean differences between groups are also presented

[a]Denotes significant group difference between the SG and CG

[b]Estimated marginal means adjusted for the covariate of baseline performance

Discussion

The aim of the present study was to determine whether a measurable change in EHC performance, following an acute exposure to SVT, could be achieved and maintained. A VS transfer test was also employed pre- and post-training to investigate if any benefits transferred to another non-trained task. Training with strobes was found to illicit statistically significant performance gains in the present study at all of the three retention test points. No statistical significance was found for either group between VS pre- and post-performance or accuracy in the VS test. There were, however, statistical differences reported between the training phase and the three retention points indicating that the treatment had some debilitation effect on practice for the SG, however, this generated positive increases in performance.

Existing research using SVT has demonstrated an improvement in visual response [30]; visual cognition [20]; and performance anticipatory timing [19]. In the later study, participants performed a simple timing prediction task using a basin anticipation timer, and the SVT group was found to improve accuracy and more consistent timing estimates immediately after training, and 10 min later. The exposure to the strobes was also similar in terms of exposure time in comparison to the present study (between 5 and 7 min, depending on performance time). We also adopted the same design using the same timescales for retention tests to enable a good comparison of findings. There are clear differences between the studies in terms of the type of stimulus or "practice" under the same time constraints. For example, Smith and Mitroff [19] carried out fifty training trials, each involving one press of a button, whereas the present study carried out twenty-four trials (480 presses) involving a sequential perception–action coupling EHC task (which are not directly comparable in their execution). Exposure to the quantity of strobe training therefore may not necessarily be the key variable, which is in agreement with Wilkins and Gray's [20] observations that adjusting strobes on time (throughout a training period) may also not be the critical factor. However, utilising different exposure frequency levels and exposure length of SVT required further exploration to clarify understanding of the mechanisms involved.

Continuous visual pickup may not be necessary for continuous motor control. In simple tasks, transitory samples may be sufficient to supplement responses from other modalities such as vestibular feedback. Eye–hand coordination comprises a more dynamic and complex coordination movement compared to the simple anticipatory tasks used in some research. Therefore, some of the complex mechanisms of coordination required for execution were not comparable to Smith and Mitroff`s [19] study. Some researchers have raised concerns over the use of representative tasks for training, particularly concerning the ecological validity of this approach (see Broadbent, Causer, Williams et al. [44] for future research directions). Differences between laboratory studies and real world have been shown for some of the perceptual-cognitive processes in terms of how close the action is to the actual sport [45]. Two components proposed for future design of training environments in sports skills displaying perception–action coupling have been identified as functionality of the task (whether the constraints a performer is exposed to are the same as those in performance environment), and action fidelity (to perform a task similar to performance environment).

Similar pre-training and training periods were also undertaken to replicate Smith and Mitroff's design. Findings show that training on the Sport Vision Trainer™ improved performance on the retention tests for both SG and CG and it is likely the results were impacted by practice effects, which would explain the improvement for the CG group. However, whilst the SG were clearly constrained by the SVT, they were significantly quicker in all retention tests. More research should be conducted on the effects of the length of exposure time, type of action performed, and frequency of exposure. Limited data exist for SVT in terms of retention periods and typically studies have assessed more immediate performance [4, 25], or 24-h retention periods [18, 26]. The 10-day retention period employed in the present study may represent an extreme delay in comparison with the short exposure to SVT. This does not allow for easy comparisons, for example Appelbaum et al. [25] alternated the frequency of the exposure rates at regular time intervals, and at set performance levels in contrast to the constant variables set for the present experiment. It is an important acknowledgement that the sequential timing of the EHC task and the stroboscopic occlusion rate are not temporally linked. The strobe is randomly effecting stimulus identification as well as response execution.

Occlusion research is typically done to explore specific aspects of information processing—e.g. a method of seeing what information is used and when, often in expertise paradigms in laboratory settings. While strobe research has set out to explore training effects by manipulating the visual environment. Whilst strobe goggles do not present true occlusion paradigms, they do offer an opportunity to manipulate continuous visual flow in the field. Whilst the present study investigated EHC as a distinct skill, research of an experimental nature including the use of both prospective and predictive information originators would be the next development in this area of investigation. This in turn should deliver a more multifaceted representation of the harmonising roles of prospective and predictive gaze and motor control processes.

A VS task was included in the test design in an attempt to test for any visual search differences following the SVT training period. No significant performance changes were elicited between the baseline and 10-day test which may indicate no long-term changes to any other fundamental visuo-perceptual mechanisms. However, due to the short exposure period employed in this study, caution should be applied to these findings. During the training period in the SG, a reduction of visual samples as the effects of restricting their field of vision took place. Their performance was negatively affected, possibly due to the disruption to their visuo-perceptual processes causing pupils to constrict and dilate. However, the CG demonstrated a more stable performance level until the final training trial. This demonstrated that strobe training had an effect during the training phase in this task, however, more research needs to identify if a longer exposure period induces performance gains in a dynamic skill such as EHC.

The findings of this study have to be considered with reference to some limitations concerning the methodological design employed. Incorporating an adequate placebo condition has been acknowledged as a serious challenge in training studies [46]. In a recent review of SVT [1] the authors suggested that a placebo is frequently not feasible, nor possible to blind participants to the experience of the intervention. They also propose that it is not possible to introduce a placebo in the case of stroboscopic vision. The CG in the present study did not observe the SG training and vice versa. The SG actually decreased completion times during SVT demonstrating the debilitating effect of the training on their ability to complete the task. There were also substantial group differences observed at baseline, which cannot be ignored. Whilst the present study tried to control for these differences by employing an ANCOVA for analysis, there is always the possibility that some training gains were not directly due to the SVT intervention. For example, some individuals may have had an increased capacity to achieve improved completion times due to others starting at a higher initial performance level. Therefore, to reduce the influence of these baseline differences, the results were analysed by adjusting the covariate of baseline performance, with the data reported as intervention effects rather than absolute values.

Conclusion and practical implications

The generality of learning in the context of this study has broad implications for theories of vision and how best to implement training protocols. Statistically meaningful inferences were observed for the SG at all retention test points. It appears that tasks requiring simple responses are of benefit alongside those requiring coordinated responses to uncertain unpredictable stimulus. This adds to the current understanding of EHC by indicating that whilst an acute exposure using SVT interferes with task execution, there are potentially no permanent effects. Research should therefore establish the most efficient use of periods, whether that is with longer exposure to the training or applying differing duration schedules for participants. As EHC and VS are critical abilities in many sporting contexts, even a small increase could have potentially profound performance effects.

Stroboscopic visual training in the present study provided an avenue of training as a means for improving EHC. Certain types of tasks are seemingly more sensitive to the effects of stroboscopic exposure than others and effects may be task specific. Alterations of spatial–temporal integration, central attention and peripheral accuracy has been shown to be affected by SVT, however, sustained spatial attention abilities have so far been unaffected. Future research should explore these mechanisms further using different exposure, frequencies, and focused identification of training drills as a complementary intervention for individual or team sports.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval All procedures were approved by institutional ethic review of the department of sport and PA, Edge Hill University, England (Approval Number SPA-REC-2014-051). This study complies with the 1964 Helsinki declaration and its later amendments.

Informed consent Informed consent was obtained for all participants included in this study.

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