Introduction

In complex decision-making situations in sport, the simultaneous processing of a high amount of visual information is considered a characteristic of highly-skilled athletes' perceptual-cognitive skills[1]. Even under time-pressure, these professionals are able to make accurate decisions.[2; 3] One reason for their superior performance is presumably found in the experts' ability to make use of peripheral vision, i.e., the ability to process information from the "corner of the eyes".[4] But is this ability, to utilize information *without* looking there, something that can be trained? In this review, we will summarize the scientific evidence behind peripheral-vision training tools that propose to improve perceptual skills in peripheral vision, and discuss whether these tools do indeed capture properties of peripheral vision.

Peripheral vision – which can be defined as vision outside the fovea (i.e., above 2.5° eccentricity[5]) – covers the largest part of the visual field's area and extends to about 214° in the horizontal, and 100° in the vertical direction.[6] Spatial resolution declines gradually with increasing distance from the center, from about ½ arcminute minimal angle of resolution (MAR) for young adults in the fovea center ("foveal bouquet"), to, e.g., twice that value at 2° eccentricity, or about ten times that value at 20°. However, since resolution in the very center is at an amazingly high value (corresponding to resolving the thickness of a human hair at 50 cm viewing distance), the practical consequences of its decrease towards the periphery are less severe than usually assumed.[6; 7] Resolution is often specified by the inverse of MAR – visual acuity – which declines according to approximately a hyperbola, which again makes the decline look rather steep.

Much more important for pattern recognition in peripheral vision is so-called *crowding*, i.e., the impairment of pattern recognition by the presence of close-by neighboring patterns[8] (see Strasburger et al.[6], Whitney & Levi[9]or Levi[10] for reviews). Important every-day tasks like reading, for example, are limited by crowding, rather than by spatial resolution.[11; 12] The distance of neighboring patterns below which the interference happens, known as the critical distance, increases with eccentricity.[13] Thus, the farther an object is located in the periphery, the greater the distance of flankers to this object need to be, to not interfere with its recognition.

When crowding is not involved, peripheral vision generally allows one to recognize (sufficiently large) objects,[14; 15] including when images are presented only for very short durations (i.e., “ensemble perception”).[14; 16–18]

In contrast to the above-listed disadvantages, motion sensitivity in peripheral vision is comparably high, as is sensitivity to flicker. Moreover, peripheral vision can be useful when eye-movements impair information processing[19–21] and was shown to be involved in the pre-processing of information from the location where the eyes are about to move.[22; 23] More generally, foveal and peripheral vision are now thought to be intimately integrated, with reorganization mechanisms for fusing pre- and postsaccadic stimuli[19] that allow “the generation of a conscious internal representation of [the] external world and the support for the guidance of our motor actions and mobility”[24] (see Stewart et al.[25] for a review).

To investigate how peripheral vision affects perception, studies in basic science use carefully controlled laboratory situations, often including eye-tracking devices for fixation control or the study of eye movement patterns for overt attention, and use simplified movement responses (e.g. a button press) or artificial visual displays. However, real-life situations like those in sports are often rather complex, and many aspects of visual processing, motor control, and complex decision making come together. Thus, the transfer of basic-science knowledge to applied situations needs extra steps of scrutiny and experimentation, where predictions from perception research need to be validated in close-to-reality settings (e.g. Grundler & Strasburger[26]).

Quantitative assessment of the use of peripheral vision in complex environments in sport requires knowing both the location of gaze and the location of attention[27–29]. In some sport-specific studies, this link has been studied using eye-tracking methods[30–34] and/or verbal reports[35–38]. Other studies used spatial occlusion techniques, where peripheral areas are occluded to investigate how the removal of that information affects motor behavior and decision making[35; 39]. Similarly, the moving-window or gaze-contingent paradigm, where information is visible only within a “window” at, or around, the current fixation point while the periphery is occluded or artificially blurred, was also used in this context[40–42]. These studies revealed three ways in which peripheral vision in sport is used: fixation between relevant information, i.e. use of a *gaze anchor*, use of peripheral vision as a *visual pivot* (when information from peripheral vision is used to decide on the next location for fixation; we call this its *preview functionality*), and use for adjusting the *foveal spot* (where the extent of peripheral processing depends on how much attention is given to foveal information; for a review see Vater et al.).[4]

Due to the complexity of sports’ situations in the field, and the rather low experimental control attainable in field studies, researchers break down the demands on peripheral vision to sub-demands and go back to laboratory research. As an example, sports like football or basketball require the concurrent tracking of multiple players for successful decision-making.[35–37] A task that is used to test whether peripheral vision is used for tracking is *Multiple Object Tracking* (MOT[43]), where multiple objects are to be tracked simultaneously amidst identically looking distractors, and fixations are frequently found *between,* rather than on, target objects.[44–48] With the MOT task, it is not only possible to examine the location of gaze but also the location of attention[49–53] (for a review see Meyerhoff et al.)[54]. Based on this extensive research data base on the MOT task, a perceptual-cognitive training tool – Neurotracker (www.neurotracker.net/) – was developed to improve, amongst others, peripheral perception and attention performance.

There are, however, many more perceptual-cognitive training tools like Neurotracker that aim to improve perceptual-cognitive skills including those in peripheral vision.[55–57] According to Hadlow et al.[55], devices that aim to improve peripheral vision skills can be categorized, for example, as (a) touch-board/screen tools (Dynavision D2, Wayne Saccadic Fixator**,** Vision Coach, Vienna Test System, Nike Sensory Station, CogniSense Neurotracker), (b) stroboscopic glasses (Nike Sparq Vapor Strobe), and (c) LED-light equipment (FitLight Trainer, Batak Pro Sports Vision). For such systems, the claim has often been made that peripheral vision can be tested or trained with the respective system (references to these claims are provided in the results section). In this topical review, we ask whether, and under what conditions, these tools do allow to test and train peripheral vision. For this aim, we used methods of systematic reviews to avoid a selection bias and searched for peer-reviewed studies that used these tools, and discuss to what degree results can indeed be linked to the use of peripheral vision.

Methods

Literature Search

The aim of our literature search was to identify the five most widely used peripheral vision tools in sports. To avoid a selection bias, we systematically searched academic databases for research articles, in a manner similar to that in systematic reviews. For this, we conducted a literature search following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines in May and June 2020 using Scopus, ScienceDirect, and PubMed as databases and, additionally, identified studies on the manufacturers' homepages. If studies were not accessible from these homepages or the databases, we used Google Scholar for the search. The searches were conducted by five independent raters (trained student assistants) and the first author. Each of the student assistants searched references for two of the following ten device keywords: *Neurotracker*, *Dynavision D2*, *FitLight*, *Vapor Strobe*, *Vision Coach*, *Wayne Saccadic Fixator* (or *Wayne Sports Vision Trainer*), *Nike Sensory Station* (or *Synaptec Sensory Station*), *Batak Pro Sports Vision*, *Vienna Test System*, and *Ultimeyes*. The first author searched for all ten devices himself, leading to two independent search results for every device (one student assistant and first author).

For the search, each rater combined the device keyword with the term *sport* (e.g. *Neurotracker* AND *sport*), and then searched in “all fields” for these terms in the search machine (a link to a search example is provided in the appendix). The results were then, if possible, limited to publications in the

English language and to publication type “article” (a procedure that also has some disadvantages, see Leeflang et al.[58] and Hoogendam et al[59]). With these filters, all conference abstracts, dissertations, book chapters, and reviews were excluded from the search. The results were exported as “.ris”, “.bib” or “.nbib” files from the respective database, and imported into the citation software ®Citavi (2018; Version 6). Identified papers were then compared between the two raters; in case the raters identified different papers, the search was repeated by both raters until the same papers were identified. In this search, we found 204 articles. Additionally, eleven cross-references were found in two other literature reviews.[60; 61] All references were saved in one Citavi database.

Screening and Eligibility

After removing duplicates with Citavi’s built-in function, we had collected 151 articles. Two student assistants and the first author then screened the abstracts and excluded articles that were not in a sports context (i.e., studies that did not use a motor task, examined sports athletes, or discussed how their results are related to sports), or were not published in a peer reviewed journal, in English language. A list of references was created in ®Microsoft Excel (2016) and used independently by all three raters. In case a paper met an exclusion criterion, a rater marked that paper in the reference list and selected, which of the exclusion criteria was met. After all three raters finished the assessment, the exclusion of papers was discussed between the three raters until consensus was reached to exclude a paper. We ended up with 109 studies for the ten devices. For the qualitative analyses, we included 93 studies for the five most-used peripheral vision training devices (Figure 1). Only the five most widely studied devices were included here to limit the length of the review.

Data Extraction and Analysis

Since the included tools use different hardware, software, and tasks, we will analyze the tools separately in three sub-chapters: (a) *System*, a description of the tool and the employed behavioral task(s); (b) *Assessment of peripheral vision*, definitions on how the tool measures peripheral vision performance, and explanations of the crucial criteria for peripheral vision testing; and (c) *Empirical findings and discussion*, which summarizes and discusses results for the extracted peripheral-vision criteria (see Table 1). In the overall discussion, we compare the devices' applicability for sports practice and research.

<<< Table 1 around here >>>

Results

In sum, we included 93 studies for the five most widely studied peripheral vision tools: Dynavision D2, CogniSense Neurotracker, Nike SPARQ Vapor Strobe, FitLight, and the Vienna Test System. Since these devices assess peripheral vision in different ways, they are characterized and discussed separately.

<<< Figure 1 around here >>>

Dynavision D2

System

The Dynavision D2™ (Dynavision International) is a light-board system used to train eye-hand coordination. It is implemented in a 1.2 m × 1.2 m (4' × 4') board, adjustable to the height of the participant, with 64 light buttons (i.e., targets) arranged in five concentric rings, and a small LCD display, mounted near the center of the board. The target location, color, frequency, and duration are adjustable; the main performance variable is the number of target-light hits.[62] Reliability of measurement is shown to be good, with retest reliability coefficients of 0.71 and 0.73 between T1-T2 and T2-T3, respectively,[63] or even very good, with coefficients of 0.88, 0.92, and 0.97 in a simple, moderate, and complex task, respectively.[62] The instructions recommend that participants perform enough familiarization trials (i.e., three to five 30-s trials), to reduce learning effects before testing.[62; 63] According to the manufacturer, the “D2™ is utilized in clinical rehabilitation to address underlying visual, cognitive, and motor deficits including visual-motor reaction time, peripheral visual awareness, executive functions, active range-of-motion, and dynamic balance”.[64] In a recent review, however, Appelbaum et al.[56] concluded that the research evidence for the efficacy as a training tool is scant.

There are three different modes of operation that participants can train with, a *proactive* (A), a *reactive* (B) and a *reaction-time* mode (C). In Mode A, a random button will illuminate and is to be turned off quickly by touching it; after that the next button will illuminate. The goal is to turn off as many buttons as possible in a pre-defined time duration (30 s or 60 s). Mode B is similar to Mode A, except that the buttons remain lit for a predefined duration (i.e., 0.1, 0.25, 0.4, 0.5, 0.75, or 1 s) and not until the participant touches the button.[63] In Mode C, the participant holds down a home button with one hand and strikes a target button with the same hand when illuminated. This procedure is repeated with the second hand. Three different sub-modes are available for Mode C (*linear* – random target adjacent to the home button, *arc* – random target from a semi-circle around the home button, and *simple* – a single, adjacent target button).[61] In all modes, the user is positioned in front of the apparatus and is either asked to fixate directly forward, or use peripheral vision to see the buttons that light up.[63] The small LCD near the center of the device often serves as a fixation point. That LCD can also be used to include an additional task where up to seven computer-selected digits are displayed briefly (between 0.01 and 1 s) at 5-s-intervals, and subjects are, for example, asked to add or multiply these digits.[63]

Assessment of peripheral vision

On the manufacturer's website, the only statement on how peripheral vision can be tested by the Dynavision D2 is: "Improving peripheral vision awareness, or the ability for the brain to more efficiently process information in your periphery, in tandem with better eye-hand coordination and quicker reaction time, enables you to react more precisely and deliberately".[64] Unfortunately, how this is to be achieved, is not answered. It appears that peripheral vision is to be trained by simply instructing participants to its use: "A user, standing before the apparatus, must strike illuminated buttons before they extinguish; at all times the user fixes his eyes directly forward and uses his peripheral vision to 'see' illuminating buttons across the span of the board".[63] Moreover, in the familiarization phase, participants are instructed "to assume a 'ready' stance (arms up, knees slightly bent) at an optimal distance from the board, keeping the eyes fixed on the center of the Dynavision board while performing the task (or on the LCD if the task involves calling digits), using peripheral vision to target illuminated buttons, and striking buttons with speed and accuracy in a darkened environment".[63] Yet, even when instructed to fixate the central LCD, participants might not use peripheral vision in every trial and instead use eye movements (saccades) to look at the target. Ruling this out would require use of an eye-tracking device for controlling participants' eye movements. Eye-tracking would allow measuring whether, and when, peripheral vision is indeed used and thereby distinguish the use of peripheral vision for detection (i.e. detecting a target light with peripheral vision and initiating a saccade to the target) from using peripheral vision for action (i.e., detecting and touching the target light without a saccade). Another way, which does not require eye-tracking (sometimes called *indirect fixation control*), is presenting the stimulus for the central visual task only briefly, thus increasing the performance costs of moving gaze off the center since display information might then be missed. The shorter the digits' display duration and the better the performance in that central task (performance must be reported as a check for manipulation), the more likely it is that peripheral vision is used to detect the target lights. However, even with short presentation times of the secondary-task information, the constant 5-s interval between these presentations could allow participants to move gaze away from the LCD: After a short learning period, participants are presumably able to predict that they must return their gaze to the center no later than 5 s after onset of the peripheral stimulus. This is enough time to look away from the LCD to the periphery, then use foveal vision for the button press, and return to the LCD before the next central stimulus is displayed. Thus, with a non-variable, predictable interval, the performance costs of eye movements away from the center can be circumvented and, as a consequence, the task no longer works as a reliable indirect fixation control. In sum, the central-digit task, when used with a constant interstimulus interval, does not guarantee that participants are indeed using peripheral vision for hitting the targets. Only a random-interval central task or, better, eye-tracking, would allow revealing whether participants are indeed using their peripheral vision.

Empirical findings and discussion

Results show that, of thirty available Dynavision D2 studies none used an eye-tracker to control the location of gaze (see Table 1). There is thus no evidence that participants are indeed using their peripheral vision for the task. With regard to indirect fixation control, thirteen studies (43%) used the LCD to display numbers or words for the secondary task. Short duration of the central presentation and short intervals between presentations are important for indirect fixation control, as explained above. From the thirteen studies that used the central display, four studies presented the foveal stimuli for one second and one for 0.75 seconds, while seven others did not report the duration. In terms of the central-stimulus intervals, six studies used a five-second interval, one a three-second interval, and another one an eight-second interval; four studies did not report the interval. While studies using the secondary central task are more likely to, indeed, measure peripheral-vision performance than those without a central task, the rather long central-stimulus presentations, and intervals between presentations, presumably allow participants to detect target lights and/or push the button using their foveal vision.

A further criterion for comparison was whether participants were instructed to use their peripheral vision. The results show that only 10 out of 30 studies (33%) did instruct participants to use peripheral vision for the task. For the subset of single-task studies – since dual-task studies implicitly have their participants fixate on the central LCD – only 4 out of 15 studies (27%) mentioned to have instructed their participants to use peripheral vision. There is some variability in wording compared to the standard instructions proposed by Klavora et al.[63] Similar to the standard instructions, for example Clark et al.[65], asked participants to “use eye discipline and to keep their eyes on the scope while using peripheral vision to see the buttons and to hit the buttons”. Hoffman et al.[66] instructed participants “to fixate their gaze on the LCD screen in the middle of the board and to keep their focus there for the entirety of the experiment”. Rather different to the standard instructions, Miller et al.[67] told participants to “keep their eyes forward, focusing on the tachistoscope, and to hit each illuminated light as quickly as possible”, and Wells et al.[68] “advised [their participants] to utilize their peripheral vision”. In the latter two examples, it is not clearly stated that participants should use their peripheral vision for detecting and hitting the illuminated buttons. Thus, for the comparison of studies, it is mandatory that participants always receive the same task instructions.

Once these instructions are standardized and the gaze position controlled, the device allows researchers to analyze the effects of eccentricity in the visual field, because the light diodes are organized on five concentric rings. One study (with gaze instructions) that analyzed performance on the five rings is by Kauffman et al.[69] The authors observed a strong effect of ring radius ($p < 0.0001$, $\eta_p^2 = 0.819$), with significant differences between each ring ($p < 0.0001$) and increasing response times with larger eccentricity. As an example, in Trial 1, one group had a response time of 612 ms for Ring 1, but almost twice that value, 1138 ms, for Ring 5). A similar result is shown in another study on the Dynavision D2, with football players.[70] Both of these results are in line with studies on the effects of viewing eccentricities (e.g., Vater et al.[44; 71] or Strasburger et al.[5]). Another study (with gaze instructions) found that response times to peripherally detected target lights are higher compared with foveally detected target lights,[72] a result that is also found with perimeter tests (e.g., Helsen & Starkes[73; 74]).

Regarding the necessary standardization of the user's operating distance from the system and the familiarization with its use demanded by Klavora et al,[62; 63] the results show that 22 out of 30 studies (73%) controlled the distances, but only 13 out of the 30 (43%) mentioned to have used familiarization trials. A feature that can be used in Mode B and C is the variation of peripheral target-light durations, which varies the peripheral monitoring time for detecting the target light (i.e., the time for monitoring and detecting the target lights). This feature was only reported to be used in 9 out of 24 studies (38%).

Taken together, the Dynavision D2 can be used for testing peripheral vision. Yet, no study so far has used eye-tracking to ensure that participants do indeed use peripheral vision for the detection of the illuminated buttons and/or for the following hand movement response to turn off the respective light. Studies using that device need to better standardize the position during the task and control for the use of the visual field, and need to use standard instructions emphasizing that participants are to use their peripheral vision at all times. Furthermore, the secondary LCD tasks should use short presentation times and variable intervals between information presentations. With this, the perceptual costs of performing saccades away from the LCD can be increased which makes the actual use of peripheral vision for light detection more probable. When publishing studies, the respective methods section should include all information related to these standardization issues, to improve the comparability between studies.

<<< Table 2 around here >>>

CogniSense NeuroTracker

System

Neurotracker (CogniSens Athletics Inc., Montreal, Canada) is a 3D-Multiple-Object-Tracking (MOT) device, assessing tracking behavior in three phases. In the first phase of each trial, eight stationary spheres appear in yellow, and (typically) four spheres are marked as targets (by highlighting in red for two seconds before they switch back to yellow). In the trial's second phase, the spheres begin to move over a period of eight seconds, all moving along a linear path through a virtual cube, bouncing off any obstacle they encounter, and continuing along their new path. In the final phase, each sphere is marked with a number, and the participant is asked to verbally recall the target spheres[75]. The tasks can be presented in a choice of devices: in a head-mounted display (HMD), on a large flat screen with the participant wearing 3D-goggles, or with 3D projectors. The size of the virtual cube covers typically between 42° and 48° of the participant's visual field. The combination of (a) an MOT, presented (b) in a large visual field, and (c) with stereoscopic presentation is thought to improve cognitive skills such as attention (sustained, divided, and selective attention, as well as inhibition).[75] According to the manufacturer's homepage (https://neurotracker.net/performance/, retrieved 6 August 2020), Neurotracker training also helps sports athletes to focus on "key play opportunities", to "filter out incoming, sensory distractions", to "stay sharp under high-pressure demands", and to "see more opportunities in any situation". In a study by Frangala et al.[76], test-retest reliability was reported to be 0.77 for twelve healthy older adults, measured seven weeks apart.

The number of targets that can be tracked is chosen by the experimenter. The spheres' speed of movement adjusts itself to the participant's performance in a staircase procedure; when all targets are successfully identified at the end of a trial, the speed is increased in the next trial, and otherwise is decreased. Average visual tracking speeds are calculated at the end of each test block. The better the tracking speed, the better attention was distributed among the targets and the better the ability to process information with peripheral vision is inferred to have been.

Assessment of peripheral vision

Peripheral vision is reasoned to be important in Neurotracker for keeping track of all targets because foveal vision can only be located on a single target at a time.[77; 78] Note that "peripheral vision", in that context, is understood not so much as a sensory skill, but is mostly short for "peripheral visual awareness"[78] (p. 98) or "sustained peripheral attention", "attentional capacity"[78] (p. 90), i.e. as a cognitive skill. This is quite misleading in so far as *peripheral vision* will be typically understood as a sensory phenomenon, with characteristics rather different from those of spatial attention (Strasburger et al.[5]; Carrasco[79]). To support an effective distribution of attention and accomplish that participants do indeed use their peripheral vision, participants should be instructed to fixate on a "visual pivot".[78] As with the Dynavision D2, it seems important to ensure that participants follow these instructions or at least keep score of when they use foveal vision elsewhere. Especially in classical 2D-MOT studies, the findings on the use of peripheral vision are rather mixed (there are a vast number of publications on the MOT task over the last thirty years; for a review see Meyerhoff et al.[54]). Participants seem to look at individual targets but tend to also look at points near the targets' centroid (i.e., the visual center of mass between the targets using peripheral vision) even if nothing is there.[44; 46; 80; 81] Looking at the centroid has the advantage of minimizing the average retinal eccentricity of the targets. The proportion of centroid vs. target fixation may depend, for example, on the number of targets[48] and the distance between objects.[45; 82] Gaze is frequently switched between targets[83] and is rarely directed at distractors.[44; 47; 80; 81] These movements of gaze are far from random – when trials are repeatedly shown to a participant, gaze patterns are very similar for the same trials.[81] Forcing participants to use certain eye-movements, however, leads to impaired tracking performance.[47] These results have two implications for Neurotracker studies: (1) not only peripheral but also foveal vision is used to keep track of targets and (2) instructing participants to use peripheral vision might result in impaired tracking performance, which would then be interpreted as poor peripheral-vision capabilities; obviously a circular reasoning.

In contrast to the Dynavision D2, Neurotracker places demands on visual but not on motor skills. For sports, these visual skills are presumably important for keeping track of multiple players, for example, to track a higher number of players or switch attention between players more quickly[78]. Thus, training effects from Neurotracker are expected to transfer to the sports context, but this needs to be empirically tested in experimental interventions with sports-transfer tasks.

Empirical findings and discussion

Within the identified 28 empirical studies for Neurotracker, there was no study using eye-tracking to check how participants were using foveal and peripheral vision. There is thus no hard evidence on whether and to what extent the participants are indeed using their peripheral vision for the task.

In only 4 out of 28 studies (15%), participants were instructed to use their peripheral vision for the task. Despite the disadvantages of instructing participants to use a certain gaze strategy (see above), doing so allows experimenters to have some kind of control over perceptual strategies. This would be relevant for the interpretation of performance in the Neurotracker tasks. Nonetheless, participants using peripheral vision to greater extents are likely to score better than participants relying more on foveal vision. [47; 48]

In 10 studies (35% of all studies), the size subtended in the visual field by the virtual cube in which targets moved was specified. In all of these studies, the virtual cube’s size was between 42° and 48° visual angle. In another ten studies (35% of all studies), the distance to and/or the size of the screen were mentioned, indicating some kind of standardized viewing positions. In eight studies (30% of all studies), however, no information on standardized viewing positions was provided. In terms of peripheral vision usage, and considering the maximum horizontal size of the visual field of about 210° degree, the demands on peripheral vision are tested in only a limited range. Thus, testing and training the far periphery is not possible with Neurotracker.

Demands placed on peripheral vision usage are different between the included studies, as can be seen, e.g., in the different number of targets that needed to be tracked. The majority of studies (68%) used four targets; 14% used three, 14% a variable number, and 4% did not mention the number of targets. Previous studies have shown that the number of targets changes the relation between foveal and peripheral vision usage.[48] Thus, peripheral vision usage is presumably different across the set of included studies.

Our results show that 18 out of 28 studies (64%) were intervention studies but that only three of these (11%) included a sports-transfer task. When looking closer into the latter, the only study finding a positive transfer effect from the training with Neurotracker to sports skills is the one by Romeas et al.[84] The study reports that Neurotracker training leads to improved decision-making in the accuracy of ball passing in soccer. In this study, an intervention group (*n* = 7) of university-level soccer players received ten Neurotracker training sessions (two per week), and was compared to an active control group (*n* = 7; the participants watched 3D soccer videos) and a passive control group (*n* = 7). In the transfer test, participants from all groups were randomly distributed over teams, and played 5 × 5 soccer matches. One experienced soccer coach, who was blinded to the experimental protocol, judged the players' accuracy of passing, dribbling, and shooting decisions. Additionally, subjective ratings of the players' decisions were collected at pre- and post-test. The data of both control groups were collapsed in the analyses (*n* = 12; two participants were excluded due to injuries). The coach's evaluations revealed improved decision-making accuracy for passing (+15%), but not for dribbling and shooting, for the intervention over the control group. Subjective confidence ratings were also higher in intervention groups compared with the control group. The overall improvement of passing skills is thus potentially related to a better peripheral-visual processing of the players' behavior.

There are, however, a number of concerns related to Romeas et al.'s[84] study. First, objectivity of these ratings cannot be assessed, given that they are from a single rater only. Other studies in this area employ several raters and report inter-rater reliability (e.g., Roca et al.[37]). Collapsing the groups for the analyses seems necessary, yet it cannot be guaranteed that the decision-making effect not is simply a placebo effect since an active control group is missing. Before considering these results as meaningful for sports practice, results need to be replicated by one or more other studies, with a larger sample size, more objective assessments, and a meaningful control task.

In the second Neurotracker intervention study with a sport-specific transfer task, there was no effect of Neurotracker training on performance in a volleyball-specific jumping task.[85] In one of the transfer-task conditions, the “dual-task high” block-jump condition, participants had to monitor the movements of a (video-recorded) attacking player in peripheral vision, and perform a move to the right or left (blocking action), depending on the attacking player’s movement direction. Since there were no improvements in this peripheral vision task after Neurotracker training, peripheral vision capabilities were either not trained or did simply not transfer to the sports tasks.

In the third relevant intervention study, by Harris et al.[86], Neurotracker training did not improve performance in a simulated driving task. In this far-transfer task, participants had to watch car-driving videos and recall the driving route; a task that is also used in military settings. This task requires operators to attend to multiple sources of information, such as recalling the route taken, and monitoring communication devices. Especially for the monitoring of communication devices, other research has found that peripheral vision is useful (e.g., Schaudt et al.[87]). Yet, Neurotracker training seems not to improve these peripheral-vision monitoring skills.

Based on the results from the other Neurotracker studies, more general cognitive skills such as working memory, sustained attention, or (distractor) inhibition may be improved with Neurotracker training (for a review, see Vater et al.[88]). Positive Neurotracker training effects have been observed in students,[89] older adults,[90] and patients with concussion symptoms.[91–93] That means that people who train with Neurotracker show better Neurotracker tracking performance. It has also been shown that elite athletes perform better in Neurotracker than less skilled athletes, who themselves perform better than participants without sports expertise.[94] Such results indicate that sports expertise leads to better Neurotracker performance, but that the improved performance is not due to improved peripheral vision capabilities.

Taken together, Neurotracker trains the tracking of multiple relevant objects in a task that shares characteristics of to those in sport-specific situations, for example when monitoring players' behavior and detection of players' actions; in the latter, peripheral vision often plays an important role.[4] Yet, Neurotracker seems to train a different set of skills and, as yet, no study showed to what extent peripheral vision is actually used during the Neurotracker task. For this, eye-tracking methods would need to be used, to monitor eye movements. Furthermore, more intervention studies are needed that use sport-specific tasks that require the processing of peripheral information. Furthermore, a larger number of participants, fair control groups, and objective measurements would need to be used.

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Nike SPARQ Vapor Strobe

System

Another way to train the use of peripheral vision is by the use of stroboscopic devices; generally an eyewear with liquid crystal plastic lenses that can alternate between transparent and opaque states[95]. While there are quite a few such devices available, we found that most research was conducted with the Nike Vapor Strobe stroboscopic glasses (Nike Inc., Beaverton, Oregon, USA). The reasoning for the use of such devices is that the stroboscopic effect forces individuals to still use the reduced visual input during the opaque state, which could lead to improved visual skills when returning to normal visual conditions.[56] The stroboscopic effect is evoked by intermittently disrupting vision; The duration of disruption can be selected in eight different difficulty levels, from *easy* (Level 1: 67 ms opaque) to *hard* (Level 8: 900 ms opaque; see Appelbaum et al[96]). The actual durations differ somewhat from those specified by the manufacturer as evidenced by measurements with high-speed cameras.[97] The clear (transparent) state's duration is 100 ms for all opaque levels.

The opaque state does not fully occlude visual information but acts rather like a neutral density filter that is difficult to see through.[95] More precisely, the main factor that changes from the clear to the opaque state is illuminance at the eye, being, e.g., reduced from an ambient room lighting of 625 lux, to 128 lux directly behind the lens. For illustration, "an illuminance of 100 lux is similar to that of a very dark overcast day; 320 lux is the minimum illuminance for office lighting recommended by the US Department of Labor".[98]

Assessment of peripheral vision

In sports coaching, stroboscopic vision training is thought to improve (amongst others) peripheral vision (e.g., see https://www.stack.com/a/nike-vapor-strobe-goggle-drills or https://www.soccerbible.com/news-archive/2011/12/nike-sparq-vapor-strobe/, both retrieved 13 August 2020). Limiting the availability of visual information during the opaque state is expected to improve processing efficiency in the clear state, which could lead to advantages under normal viewing conditions.

However, that reasoning is highly speculative and there is yet no evidence for an impact on peripheral vision. Testing of eye movements is furthermore not straight forward with the shutter glasses because standard eye cameras do not work in that situation. Similar to the situation with Neurotracker, one might look for transfer tests that assess peripheral vision performance after stroboscopic training.

Empirical findings and discussion

In our systematic search, we identified 15 studies on the Nike strobe glasses; the results are presented in Table 4. From the 15 included studies, nine (60%) were intervention studies. In these, strobe glasses were used in a variety of tasks, like soccer dribbling,[96; 99] throwing and catching,[96; 100; 101] baseball batting,[102; 103] or were used during general training.[104] There were two intervention studies that included a peripheral-vision transfer task. The latter revealed that it is *not* peripheral vision that is improved with stroboscopic training, but rather foveal vision (i.e. the ability to process foveal information quicker; [100; 101]; for a discussion see also Wilkins & Applbaum[105]). In dual-task situations with a simultaneous foveal and a peripheral task (the location of peripheral stimuli was to be remembered), peripheral performance did not increase with stroboscopic training.[100] Moreover, MOT performance – which we related to peripheral vision earlier – was not improved with stroboscopic training. Other intervention studies have shown that stroboscopic training is rather linked to anticipatory tasks,[95; 98] to other basic visual skills,[102] and to eye-hand coordination,[102; 106] but does not affect visual search performance[106] or the ability to catch balls.[101]

A variety of occlusion intervals have been used in these studies. In four studies, Levels 1-6 were used and adapted to the performance level in the intervention task. In three studies, only Level 3 was used, i.e., a duration of the opaque state of 150 ms, followed by a clear state of 100 ms duration. In the other studies, a set of levels was used to vary the visual processing demands. A general result was that performance decreases with longer occlusions in that, for example, reaction times increased[97] or dribbling performance in soccer was impaired.[99] Short or long occlusion intervals did not appear to affect the processing in peripheral vision differently but longer intervals led to improved short-term memory performance.[96; 103]

The duration of interventions in the studies ranged from a few minutes[95; 106] to that of an entire baseball season.[103] Short interventions can already lead to improvements, for example, in an anticipatory timing task.[95] In long intervention studies, the effects are less clear because strobe glasses were mostly used in combination with other visual skill trainings (e.g., Clark et al.[70] and Appelbaum et al.[102]).

Nike appears not to advertise their strobe glasses anymore, or at least there was no information available on their webpage at the time of writing. One reason might be the risk of evoking an epileptic attack; such attacks occasionally occur at strobe rates between 3 and 30 Hz (https://www.epilepsysociety.org.uk/photosensitive-epilepsy, retrieved 13 August 2020). The frequency of the stroboscopic glasses (1 to 6 Hz) is in that typical range. If sports practitioners can guarantee that their athletes have no risk of epileptic attacks and are interested in commercial eyewear, there are other strobe glasses still on the market (e.g., PLATO Visual Occlusion Spectacles; Senaptec Strobe; Visionup Strobe Glasses), which also permit greater control over the duration of clear and opaque states. For example, the PLATO goggles or Senaptec strobe glasses occlude visual information much more in the opaque state, which affects performance differently than do the Vapor strobe glasses (see, e.g., Benett et al[97]). In sum, training with the Nike SPARQ Vapor Strobe glasses appears not to lead to improved peripheral vision performance. It rather seems that short-term memory is trained with this training device and that improvements help to process foveal information quicker.

<<< Table 4 around here >>>

FitLight

System

FitLight (Sport Corp. Ontario, Canada) is a wireless LED-light system that comes with disc-like sensors (10 cm in diameter), used as targets, that need to be deactivated by the athlete. They can be placed at any location and are used to create complex reaction-time tasks. The target light's color is programmable. The FitLight system is claimed to improve peripheral vision, as well as speed and agility, spatial awareness, cognition processing function, reaction and response time, fine motor control, and coordination (https://www.fitlighttraining.com/sports-fitness/, retrieved 10 August

2020). According to the webpage, the system is used by many professional sports clubs, like the NBA-clubs Cleveland Cavaliers and the Golden State Warriors (basketball), Manchester United, FC Chelsea and FC Barcelona (soccer), and by the military (U.S. Air Force).

Because the FitLight sensors can be arranged in many different ways, the reliability results differ depending on the experimental setup. When eight sensors are placed in a semi-circle on a table, with 20 cm separation between them, the inter-rater correlation coefficient (ICC) is between 0.85 (for a difficult task) and 0.92 (for a simple task).[107] In another study, reliability in a similar setting is reported to be 0.72.[108] In more complex task setups requiring full-body movements and deactivations with the limbs, the ICC is reported to be between 0.60 (moderate) and 0.94 (excellent) for thirteen different tests. For a variety of single-leg hop tests, reliability between two test days is between 0.87 and 0.98.[109]

Assessment of peripheral vision

It seems that FitLight training would automatically improve peripheral vision because targets can be placed anywhere in a large region of the visual field. However, the manufacturer does not explain how, exactly, peripheral vision is trained. Reorienting and finding the next target light presumably involves the detection of that light in peripheral vision. The flexibility of where to place the sensors allows creating complex situations that require the processing of peripheral information. Alternatively, however, the user might also quickly scan the environment with saccadic eye-movements, thereby using foveal vision for target detection. The interval between target lights can be adjusted (between 0.1 and 3.0 seconds)[110] and – similar to the Dynavision D2 – shorter intervals between lights would make the use of peripheral vision more effective (avoiding effects of saccadic suppression). Different target light durations can be selected, to stress peripheral vision over a self-selected amount of time. Peripheral vision usage may also depend on the requested motor responses because light sensors can be deactivated with any body part.

Empirical findings and discussion

In total, twelve studies with the FitLight system were identified and results are shown in Table 5. None of the studies used eye-tracking to monitor the participants' gaze behavior, and only two studies instructed participants to fixate straight ahead and make use of peripheral vision. Participants thus could have used saccades to scan for target lights before deactivating them.

It is nevertheless likely that participants did indeed use peripheral vision because multiple target lights were placed over large parts of the visual field. In the listed set of studies, targets were placed at horizontal eccentricities ranging from 85° to 360°. Thus, in some studies body turns were required to pick up the target information. The demands to detect target lights with peripheral vision increases with the number of targets. Between 5 and 10 of the targets were placed in the visual environment. Performance differences were investigated for targets in the upper and lower visual field.[111; 112]

Reducing the interval between target-light activations limits the time to search for the light and makes the use of peripheral vision more likely. In 9 out of 12 studies (75%), random or pseudo-random intervals between target lights were chosen, with intervals as short as 0.1 s.[110] Reorienting gaze in that short interval is not possible, so if a participant did deactivate the target light, gaze was either directed there by chance or the target must have been perceived with peripheral vision. Since the intervals are random, anticipating and deliberately searching for target lights does not help, in particular since saccades are associated with the costs of missing a target light that is switched off quickly. Using peripheral vision is thus presumably more functional.

Peripheral vision is used with widely differing durations of test or training sessions, as shown by the number of series and reactions conducted in the included studies. The minimum number of reactions per series is one,[109] and the maximum is 64.[113] We do not know whether or how fatigue affects the use of peripheral vision and thus do not know whether the use of peripheral vision will change between the beginning and end of a long sequence.

As explained earlier, placing the targets in large parts of the visual environment allows researchers testing the coupling between peripheral perception and action. In the included studies, motor responses from hands and arms (five studies), legs (two studies), or full-body movements (six studies) were requested. Since peripheral vision is known to be important for orientation in space, full-body movements, in particular, presumably require the processing of peripheral information.[114]

However, taken together, there is no evidence that peripheral vision is indeed used to detect target lights in the FitLight system, and research is needed on that question. There are indeed many task characteristics, like the number of targets, target-light intervals, the large visual field within that targets are placed in, that make it likely that peripheral vision is indeed used, but direct evidence is missing. For sports practitioners, it is also worth noting that tests on executive functions (e.g., inhibition of responses to irrelevant color LEDs; see, for example, Laessoe et al[112], van Cutsem et al.[113], or Wilke et al.[115]), or systems for balance control[116] can be combined with the FitLight system.

<<< Table 5 around here >>>

Vienna Test System

System

The Vienna Test System, developed by Schuhfried GmbH (Moedling, Austria), allows researchers testing a variety of cognitive and perceptual abilities including, among others, peripheral perception.[117] For the respective subtest (named “PP”), panels with light diodes are attached in an angle at the right and left of a central screen, on each of which 64 × 8 green LEDs are mounted in 64 columns and 8 rows. With both panels attached, the overall horizontal measurement range for the visual field spans approximately 180 degrees (W. Grundler, personal communication, 22.9.2020) to 190 degrees,[118] depending on viewing distance. Subjects perform a central tracking task and, simultaneously, a peripheral perception task. In the central task, participants keep a moving ball within the cross-hair on the central screen. For the peripheral task, green-light stimuli that are to be ignored move somewhat randomly toward the periphery and the subject is to react to occasionally occurring vertical bars, also moving outwards (W. Grundler, personal communication). In the user manual, the reliability is stated as $r = 0.96$ and $r = 0.98$ for the FOV measurement and the tracking task, respectively. Norms are provided for both measures, based on an assessment of 351 adults. Performing the test requires approximately 15 minutes. According to the manufacturer, logical content validity or high face validity can be assumed.[117]

Assessment of peripheral vision

Targets for the peripheral task are vertical LED bars on one of the 64 horizontal positions blinking for 60 ms and participants press a foot pedal when detecting the target. In total, 80 target lights are presented (40 on the right and left, respectively). The first dependent variable, peripheral reaction time, is measured as the time from the appearance of the target to the foot pedal response. It is measured separately for the right and left part of the visual field. The second dependent variable is the angular size of the subject's horizontal visual field (dubbed "field of vision, FOV", by Schuhfried; note that the terms "field of vision" and "field of view" are both ambiguous in that eye movements are variably included or excluded). It is calculated from the subject's viewing distance, measured by an ultrasound distance sensor at the moment the foot pedal is actuated.

Based on these descriptions, it appears peripheral vision can be examined with the system: A central task requires participants to keep fixating the monitor, while a simultaneous peripheral task requires processing information from the visual periphery. Besides controlling participants' gaze by a central task, additional control is provided by recording head position. There is no information about the eccentricity of the individual target lights and the calculated reaction time is presumably the average of all detections. An adaptive algorithm on the position of these lights ensures that there are at least 50% detected targets.[119]

Empirical findings and discussion

The results of 7 studies with the Vienna Test System's peripheral perception test (PP) presented in Table 6 show that, so far, no intervention study was conducted. One study, however, showed that it is possible to improve performance after one training session.[120] The system was mainly used to test differences between groups, different conditions, or retest reliability. Results showed that athletes respond faster than non-athletes[119; 121] and that peripheral reaction times are shorter after physical exercises.[122; 123] One study found differences in peripheral reaction times in the left, compared with the right visual field.[124] Results on the visual field showed that increased mental fatigue decreased the visual field by 8.3° (from 189.9° to 181.6°)[118] similar to physical exercise in physically active men.[122] Second-division handball players, however, do not have a smaller horizontal visual field after an anaerobic exercise and, to the contrary, showed improved performance in the PP (in the number of correct reactions and omitted reactions).[123] Another study, which was published after our systematic search, but should nevertheless be noted here, found that perceptual-cognitive training can improve peripheral vision performance – measured with the Vienna Test System before and after the intervention – of young football players.[125]

Overall, the combination of a foveal and a peripheral task is an elegant way to examine peripheral perception without using eye-tracking fixation control. If people have to fixate on the central display to perform well in a foveal task, participants likely do not use eye-movements to detect the peripheral target. The downside of that method is that there are dual-task costs. This potentially explains the moderate to poor reliability for the left (.74) and right (.58) visual angle, respectively.[120] Therefore, the peripheral vision test in the Vienna Test System "might not be precise enough to detect improvements caused by PV interventions in sports research".[120] The system is not appropriate for testing peripheral reaction times for different viewing eccentricities, because it only calculates the overall peripheral reaction time. It seems, however, a useful measurement system for peripheral reaction times and peripheral movement detection, for which good reliability was reported.[117]

<<< Table 6 around here >>>

Overall discussion and outlook

The aim of this topical review was to identify peripheral vision testing and training tools that were most frequently used in sports research, to then discuss whether, and how, they measure and train peripheral vision. The results show that touch-board/screen tools (Dynavision D2: 32 studies, Cognisense Neurotracker: 28 studies and the Vienna Test System: 7 studies) are used the most but that there is also a significant body of research on strobe glasses (Nike Sparq Vapor Strobe: 15 studies) and LED-light equipment (FitLight Trainer: 12 studies). There is only limited evidence, however, that peripheral vision is indeed used in these systems, mainly because eye-movements were not recorded. Nevertheless, the task characteristics (i.e., secondary tasks, gaze instructions, positioning of targets in the visual environment, motor responses demanded) suggest that peripheral vision does play an important role for most devices.

Maybe due to the applied nature of many studies, experimental control over gaze behavior seems not have been prioritized in the studies surveyed. Compared to the other systems, studies using the Dynavision D2 and the Vienna Test System appear to have the most experimental control over perceptual variables (e.g., viewing eccentricity), considering that the peripheral target positions can be manipulated and that the observer's viewing distance – which defines the size of the tested visual field – is mostly standardized. An asset of these devices is their employment of a secondary, foveal task. With such a task, participants are likely to fixate there and not focus on the peripheral targets because foveal acuity is required to solve the central, secondary task. This kind of ensuring fixation is frequently used in perimetry (e.g., Kasten et al [126], or Poggel et al.[127]) and is sometimes termed *indirect fixation control*. These dual-task situations seem to be found also in sports, for example, when focusing on the direct opponent in soccer and, at the same time, process information from another player in the periphery.[38; 128] However, the dual task approach represents a situation of divided spatial attention and is thus likely to affect peripheral attentional performance in an uncontrolled way, making comparisons between systems that do, or do not, use the secondary task difficult (cf. Carrasco[79]).

In sports, peripheral vision is needed to process information coming from up to very large eccentricities. In combat sports, for example, it is known that gaze is often fixated on the opponent's head or chest, and that attacks from arms and legs are detected with peripheral vision.[30; 129; 130] The fact that athletes fixate high on the opponent's body but are still able to react to leg attacks, suggests that they can process the information from the opponent's leg at a very large eccentricity. These processing demands can be simulated with the Dynavision D2 and the Vienna Test System (in the horizontal direction) because peripheral stimuli can be presented at large eccentricities. For combat sports, the Dynavision D2 might be even more suitable for testing because peripheral stimuli need to be deactivated with hand responses, which is similar to a defensive movement when blocking the attack from the opponent. In contrast, the Vienna Test System demands foot-pedal responses, which could, maybe, be linked to the initiation of a movement response to a certain direction. Both assumptions could be tested in future validation studies.

The processing of movements is essential in sports; be it the movement of a ball, or a player moving towards the basket or goal. There is evidence from eye-tracking studies in sports showing that athletes seem to process a lot of movement information with peripheral vision (e.g., Ryu et al.[41; 42] or Williams & Davids[35]). Testing the ability to process movements is not possible with the Vienna Test System or the Dynavision D2, because targets simply need to be detected and are not moving. Neurotracker, in contrast, requires to continuously update information from moving targets, similar to sports. There is, however, no Neurotracker study that has yet used eye-tracking devices to confirm that peripheral vision is used (in contrast to the classical MOT studies).[44–48] Also, different to the situation in many sports, Neurotracker stimuli are presented in a rather narrow visual field (approx.

45°), and no motor responses are requested. The link between peripheral perception and action is mainly made in intervention studies. In these, improved Neurotracker performance was expected to transfer to driving skills, football decision making skills, or volleyball skills, all of them requiring the processing of information for multiple movements in the periphery. The current research state, however, shows that there are either no transfer effects (driving and volleyball) or that there appear to be transfer effects that would need to be replicated with more objective assessments and larger sample sizes (soccer).[88]

As in the combat sports example, the processing of peripheral information is often linked to the initiation of movement responses in complex decision-making situations.[4] The FitLight system allows researchers to create such a complex visual environment typically found in sports. The targets can be placed anywhere in the environment and full-body movement responses for turning off the target lights can be requested. It is possible to measure reaction and movement times for targets placed at different eccentricities. But, based on the research evidence so far, it is not clear whether participants are indeed using their peripheral vision, as claimed. Instead, foveal visual-search skills might be more important. Eye-tracking research is needed here, to experimentally test the relative importance of foveal and peripheral vision. With the FitLight system, one could increase the importance of peripheral vision by decreasing the predictability of the next target location with a random target-location sequence (the same could be done with the Dynavision D2 system). If the next target location is not predictable, it is unlikely that foveal vision is already located at the next target location. As a consequence, the preview functionality of peripheral vision (i.e., detecting a target in peripheral vision first for eliciting a saccade thereto), could become more important. This functionality has also been discussed in vision science (e.g., Henderson[131]) and sport science (e.g., Vater et al.[4]).

Another, more attention-related skill that is often linked to peripheral-vision processing is the ability to inhibit irrelevant stimuli. In soccer decision making, for example, experts disregard players positioned far away from the ball, although they are in their visual field.[36] The FitLight system allows researchers to create such conditions where only specific target-light colors require a reaction while others are to be inhibited (i.e., should not be responded to). Similarly, the Neurotracker task includes objects that do not need to be tracked. It should be noted, though, that different neural processes are assumed to be involved for the two devices: While Neurotracker requires attentional suppression of visual distractors,[132; 79] FitLight requires inhibiting a motor response (i.e., "to deliberately control prepotent responses", c.f. Latzman & Markon[133]).

One difficulty for future research will certainly be to disentangle the role of memory and (peripheral) vision. It cannot be ruled out that sports athletes make decisions based on their extensive knowledge base (memory) and not based on their visual information processing. An example: If a soccer player knows about the action preferences of the opponent, there is little need to always have him or her in peripheral vision. For the devices reviewed here, research has shown that Neurotracker training improves working memory, and that strobe glass training improves short-term memory. For both devices, no improvements in peripheral vision performance have been observed. Instead, research for the strobe glasses suggests improvements in foveal rather than peripheral vision. Future research should therefore focus on the interaction between memory and vision, as both processes are important in sports.

A limitation of this review is that not all of the studies included are focused on the use of peripheral vision. Other, related topics were in the center of interest, like attention skills (visual awareness, spatial attention, working memory, inhibition) or the effects of a certain training intervention on reaction times. Nevertheless, based on the task characteristics and methods used, these studies can still help researchers to better understand the role of peripheral vision. Another limitation is that we limited our search to three general databases (with additional searches in Google Scholar). Including other, more specialized databases such as PsychInfo might reveal more published studies that would be relevant for the current topic and reduce the likelihood of a publication bias. A previous review on peripheral vision in sports, however, used the same databases as the current one.[4]

Summing up, a number of peripheral vision tools are available on the market. While some tools have been used mainly as testing devices (Dynavision D2, Vienna Test System), others have mainly been used for training (Cognisense Neurotracker, FitLight, Nike SPARQ Vapor Strobe). With our analyses of the five most widely-studied peripheral vision tools, we were able to show that devices like the Dynavision D2 and the Vienna Test System allow testing the ability to detect peripheral targets with comparably high experimental control and (simple) action responses. Neurotracker focuses on the ability to process target movements over a longer period of time, concentrating on the distribution of spatial attention and working memory components, and is often used to train cognitive skills (peripheral awareness). FitLight is best suited to create complex environments with gross motor responses, where the preview functionality of peripheral vision might be tapped. If and how peripheral vision is tested and trained with the Nike Sparq Vapor Strobe is not clear. Future research with the reviewed devices should certainly include eye-tracking if possible, to investigate whether visual search strategies support the expected use of peripheral vision. Furthermore, the interaction between memory, attention, and perception needs further research, especially for Neurotracker. Once it is known how peripheral vision is used with these tools, intervention studies could show whether device-specific improvements will help to improve peripheral vision performance in sport-specific situations.

References

1. Mann DY, Williams AM, Ward P, et al. Perceptual-cognitive Expertise in Sport. A Meta-Analysis. J Sport Exerc Psychol 2007;29:457–78.

2. Gredin NV, Bishop DT, Broadbent DP, et al. Experts Integrate Explicit Contextual Priors and Environmental Information to Improve Anticipation Efficiency. J Exp Psychol Appl 2018.

3. Vater C, Roca A, Williams AM. Effects of Anxiety on Anticipation and Visual Search in Dynamic, Time-Constrained Situations. Sport Exerc Perform Psychol 2016;5:179–92.

4. Vater C, Williams AM, Hossner EJ. What do we See out of the Corner of our eye? The role of visual pivots and gaze anchors in sport. Int Rev Sport Exerc Psychol 2020;13:81–103.

5. Strasburger H, Rentschler I, Jüttner M. Peripheral Vision and Pattern Recognition. A review. J Vis 2011;1-82.

6. Strasburger H. Seven myths on crowding and peripheral vision. i-Perception 2020;11:1-46.

7. Rosenholtz R. Capabilities and Limitations of Peripheral Vision. Annu Rev Vision Sci 2016;2:437–57.

8. Stuart JA, Burian HM. A Study of Separation Difficulty. Am J Ophthalmol 1962;53:471–7.

9. Whitney D, Levi DM. Visual Crowding: A Fundamental Limit on Conscious Perception and Object Recognition. Trends Cognit Sci 2011;15:160–8.

10. Levi DM. Crowding—An Essential Bottleneck for Object Recognition: A Mini-Review. Vision Res 2008;48:635–54.

11. Pelli DG, Tillman KA, Freeman J, et al. Crowding and Eccentricity Determine Reading Rate. J Vis 2007;7:20.1-36.

12. Pelli DG, Tillman KA. The Uncrowded Window of Object Recognition. Nat Neurosci 2008;11:1129–35.

13. Bouma H. Interaction Effects In Parafoveal Letter Recognition. Nature 1970;226:177–8.

14. Larson AM, Loschky LC. The Contributions of Central versus Peripheral Vision to Scene Gist Recognition. J Vis 2009;9:6.1-16.

15. Thorpe SJ, Gegenfurtner KR, Fabre-Thorpe M, et al. Detection of animals in natural images using far peripheral vision. Eur J Neurosci 2001;14:869–76.

16. Wolfe B, Dobres J, Rosenholtz R, et al. More Than The Useful Field: Considering Peripheral Vision In Driving. Appl Ergon 2017;65:316–25.

17. Haberman J, Whitney D. Ensemble Perception. In: Wolfe JM, Robertson L, eds. From perception to consciousness: Oxford University Press; 2012:339–49.

18. Sweeny TD, Haroz S, Whitney D. Perceiving Group Behavior: Sensitive Ensemble Coding Mechanisms for Biological Motion of Human Crowds. J Exp Psychol Hum Percept Perform 2013;39:329–37.

19. Binda P, Morrone MC. Vision during Saccadic Eye Movements. Annu Rev Vision Sci 2018;4:193–213.

20. Ross J, Morrone MC, Burr DC. Compression of Visual Space before Saccades. Nature 1997;386:598–601.

21. Ross J, Morrone MC, Goldberg ME, et al. Changes in Visual Perception at the Time of Saccades. Trends Neurosci 2001;24:113–21.

22. Findlay JM, Gilchrist ID. Visual Attention: The Active Vision Perspective. In: Jenkin M, Harris L, eds. Vision and attention. New York: Springer; 2001:83–103.

23. Nuthmann A. How Do The Regions of The Visual Field Contribute to Object Search in Real-World Scenes? Evidence From Eye Movements. J Exp Psychol Hum Percept Perform 2014;40:342–60.

24. Gegenfurtner KR. The Interaction between Vision and Eye Movements. Perception 2016;45:1333–1357.

25. Stewart EEM, Valsecchi M, Schütz AC. A Review of Interactions between Peripheral and Foveal Vision. J Vis 2020;20:1–35.
26. Grundler W, Strasburger H. Visual Attention Outperforms Visual-Perceptual Parameters Required By Law As An Indicator of On-Road Driving Performance. PLoS One 2020;15:e0236147.
27. Vater C, Kredel R, Hossner EJ. Examining The Functionality of Peripheral Vision: From Fundamental Understandings to Applied Sport Science. Current Issues in Sport Science 2017 :2:010.
28. Afonso J, Garganta J, McRobert A, et al. The Perceptual Cognitive Processes Underpinning Skilled Performance in Volleyball. Evidence From Eye-Movements and Verbal Reports of Thinking Involving An in Situ Representative Task. J Sports Sci Med 2012;11:339–45.
29. Davids K. The Role of Peripheral Vision in Ball Games: Some Theoretical and Practical Notions. Eur Phy Educ Rev 1984;7:26–40.
30. Piras A, Pierantozzi E, Squatrito S. Visual Search Strategy in Judo Fighters during The Execution of The First Grip. Int J Sports Sci Coach 2014;9:185–97.
31. Piras A, Raffi M, Perazzolo M, et al. Microsaccades and Interest Areas during Free-Viewing Sport Task. J Sports Sci 2017;37:1–8.
32. Nagano T, Kato T, Fukuda T. Visual Search Strategies of Soccer Players in One-On-One Defensive Situations on the Field. Percept Mot Skills 2004;99:968–74.
33. Nagano T, Kato T, Fukuda T. Visual Behaviors of Soccer Players While Kicking With The Inside of The Foot. Percept Mot Skills 2006;102:147–56.
34. Vansteenkiste P, Vaeyens R, Zeuwts L, et al. Cue Usage in Volleyball. A Time Course Comparison of Elite, Intermediate, and Novice Female Players. Biol Sport 2014;31:295–302.
35. Williams AM, Davids K. Visual Search Strategy, Selective Attention, and Expertise in Soccer. Res Q Exerc Sport 1998;69:111–28.
36. Roca A, Ford PR, McRobert AP, et al. Identifying The Processes Underpinning Anticipation and Decision-Making in A Dynamic Time-Constrained Task. Cogn Process 2011;12:301–10.
37. Roca A, Ford PR, McRobert AP, et al. Perceptual-Cognitive Skills and Their Interaction as A Function of Task Constraints in Soccer. J Sport Exerc Psychol 2013;35:144–55.
38. Vater C, Luginbühl SP, Magnaguagno L. Testing the Functionality of Peripheral Vision in A Mixed-Methods Football Field Study. J Sports Sci 2019;37:2789-2797.
39. Panchuk D, Vickers JN. Using Spatial Occlusion to Explore The Control Strategies Used in Rapid Interceptive Actions: Predictive Or Prospective Control? J Sports Sci 2009;27:1249–60.
40. Cañal-Bruland R, Lotz S, Hagemann N, et al. Visual Span and Change Detection in Soccer: An Expertise Study. J Cogn Psychol 2011;23:302–10.
41. Ryu D, Abernethy B, Mann DL, et al. The Role of Central and Peripheral Vision in Expert Decision Making. Perception 2013;42:591–607.
42. Ryu D, Abernethy B, Mann DL, et al. The Contributions of Central and Peripheral Vision to Expertise in Basketball. How Blur Helps to Provide A Clearer Picture. J Exp Psychol Hum Percept Perform 2015;41:167–85.
43. Pylyshyn ZW, Storm RW. Tracking Multiple Independent Targets. Evidence for a Parallel Tracking Mechanism. Spat Vis 1988;3:179–97.
44. Vater C, Kredel R, Hossner EJ. Detecting Target Changes in Multiple Object Tracking With Peripheral Vision. More Pronounced Eccentricity Effects for Changes in Form Than in Motion. J Exp Psychol Hum Percept Perform 2017;43:903–13.
45. Vater C, Kredel R, Hossner EJ. Disentangling Vision and Attention in Multiple-Object Tracking. How Crowding and Collisions Affect Gaze Anchoring and Dual-Task Performance. J Vis 2017;17:21.
46. Fehd HM, Seiffert AE. Eye Movements during Multiple Object Tracking: Where Do Participants Look? Cognition 2008;108:201–9.

47. Fehd HM, Seiffert AE. Looking At The Center of The Targets Helps Multiple Object Tracking. J Vis 2010;10:19.
48. Zelinsky GJ, Neider MB. An Eye Movement Analysis of Multiple Object Tracking in A Realistic Environment. Visual Cognit 2008;16:553–66.
49. Vater C. How Selective Attention Affects The Detection of Motion Changes With Peripheral Vision in MOT. Heliyon 2019;5:e02282.
50. Cavanagh P, Alvarez GA. Tracking Multiple Targets with Multifocal Attention. Trends Cognit Sci 2005;9:349–54.
51. Yantis S. Multielement Visual Tracking. Attention and Perceptual Organization. Cogn Psychol 1992;24:295–340.
52. Holcombe AO, Chen WY. Splitting Attention Reduces Temporal Resolution From 7 Hz for Tracking One Object to <3 Hz When Tracking Three. J Vis 2013;13:12.
53. Wolfe JM, Alvarez GA, Horowitz TS. Attention Is Fast But Volition Is Slow. Nature 2000;406:691.
54. Meyerhoff HS, Papenmeier F, Huff M. Studying Visual Attention Using The Multiple Object Tracking Paradigm. A Tutorial Review. Atten Percept Psychophys 2017;79:1255–74.
55. Hadlow SM, Panchuk D, Mann DL, et al. Modified Perceptual Training in Sport: A New Classification Framework. J Sci Med Sport 2018;21:950–8.
56. Appelbaum LG, Erickson GB. Sports Vision Training: A Review of the State-Of-The-Art in Digital Training Techniques. Int Rev Sport Exerc Psychol 2018;11:160–89.
57. Harris DJ, Wilson MR, Vine SJ. A Systematic Review of Commercial Cognitive Training Devices: Implications for Use in Sport. Front Psychol 2018;9:709.
58. Leeflang MMG, Scholten RJPM, Rutjes AWS, et al. Use of Methodological Search Filters to Identify Diagnostic Accuracy Studies can Lead to the Omission of Relevant Studies. J Clin Epidemiol 2006;59:234–40.
59. Hoogendam A, Vries Robbé PF de, Stalenhoef AFH, et al. Evaluation of Pubmed Filters Used for Evidence-Based Searching: Validation Using Relative Recall. J Med Libr Assoc 2009;97:186–93.
60. Ong NCH. The Use of the Vienna Test System in Sport Psychology Research: A Review. Int Rev Sport Exerc Psychol 2015;8:204–23.
61. Ong NCH. The Use of Dynavision in Sport and Exercise Research: A Review. Int J Sport Exerc Psychol 2018:1–20.
62. Klavora P, Gaskovski P, Forsyth RD. Test-Retest Reliability of Three Dynavision Tasks. Percept Mot Skills 1995;80:607–10.
63. Klavora P, Gaskovski P, Forsyth RD. Test-Retest Reliability of the Dynavision Apparatus. Percept Mot Skills 1994;79:448–50.
64. Dynavision International. Home | Dynavision. Available at: https://www.dynavisioninternational.com. Accessed June 24, 2020.
65. Clark JF, Graman P, Ellis JK, et al. An Exploratory Study of the Potential Effects of Vision Training on Concussion Incidence in Football. Optometry & Visual Performance 2015 :116–25.
66. Hoffman JR, Williams DR, Emerson NS, et al. L-Alanyl-L-Glutamine Ingestion Maintains Performance during A Competitive Basketball Game. J Int Soc Sports Nutr 2012;9:1–8.
67. Miller RA, Rogers RR, Williams TD, et al. Effects of Protective American Football Headgear on Peripheral Vision Reaction Time and Visual Target Detection in Division I NCAA Football Players. Sports (Basel) 2019;7:231–8.
68. Wells AJ, Hoffman JR, Beyer KS, et al. Reliability of the Dynavision™ D2 for Assessing Reaction Time Performance. J Sports Sci Med 2014;13:145–50.
69. Kauffman DC, Clark JF, Smith JC. The Influence of Sport Goggles on Visual Target Detection in Female Intercollegiate Athletes. J Sports Sci 2015;33:1117–23.
70. Clark JF, Colosimo A, Ellis JK, et al. Vision Training Methods for Sports Concussion Mitigation and Management. J Vis Exp 2015;99:e52648.

71. Vater C, Klostermann A, Kredel R, et al. Detecting Motion Changes With Peripheral Vision: On The Superiority of Fixating Over Smooth-Pursuit Tracking. Vision Res 2020;171:46–52.

72. Clark JF, Ellis JK, Burns TM, et al. Analysis of Central and Peripheral Vision Reaction Times in Patients with Postconcussion Visual Dysfunction. Canadian Academy of Sport Medicine 2017;27:457–61.

73. Helsen WF, Starkes JL. A Multidimensional Approach to Skilled Perception and Performance in Sport. Appl Cognit Psychol 1999;13:1–27.

74. Schiefer U, Strasburger H, Becker ST, et al. Reaction Time in Automated Kinetic Perimetry: Effects of Stimulus Luminance, Eccentricity, and Movement Direction. Vision Research 2001;41:2157–64.

75. Parsons B, Magill T, Boucher A, et al. Enhancing Cognitive Function Using Perceptual-Cognitive Training. Clin EEG Neurosci 2014;47:37–47.

76. Fragala MS, Beyer KS, Jajtner AR, et al. Resistance Exercise May Improve Spatial Awareness and Visual Reaction in Older Adults. J. Strength Cond. Res. 2014;28:2079–87.

77. Beauchamp P, Faubert J. Visual Perception Training: Cutting Edge Psychophysics and 3d Technology Applied to Sport Science. High Performance CIRCuit-e-Journal 2011;1:12–6.

78. Faubert J, Sidebottom L. Perceptual-Cognitive Training of Athletes. J Clin Sport Psychol. 2012;6:85–102.

79. Carrasco M. Visual attention: The past 25 years. Vision Res 2011;51:1484–525.

80. Vater C, Kredel R, Hossner E-J. Detecting Single-Target Changes in Multiple Object Tracking. The Case of Peripheral Vision. Atten Percept Psychophys 2016;78:1004–19.

81. Lukavský J. Eye Movements in Repeated Multiple Object Tracking. J Vis 2013;13:9.

82. Zelinsky GJ, Todor A. The Role of "Rescue Saccades" in Tracking Objects through Occlusions. J Vis 2010;10:1–13..

83. Elfanagely O, Haladjian HH, Aks D, et al. Eye-Movement Dynamics of Object-Tracking. J Vis 2011;11:280.

84. Romeas T, Guldner A, Faubert J. 3D-Multiple Object Tracking Training Task Improves Passing Decision-Making Accuracy in Soccer Players. Psychol Sport Exerc 2016;22:1–9.

85. Fleddermann M-T, Heppe H, Zentgraf K. Off-Court Generic Perceptual-Cognitive Training in Elite Volleyball Athletes: Task-Specific Effects and Levels of Transfer. Front Psychol 2019;10:1599.

86. Harris DJ, Wilson MR, Smith SJR, et al. Testing The Effects of 3d Multiple Object Tracking Training on Near, Mid and Far Transfer. Front Psychol 2020;11:196.

87. Schaudt WA, Caufield KJ, Dyre BP. Effects of a Virtual Air Speed Error Indicator on Guidance Accuracy and Eye Movement Control during Simulated Flight. Proc Hum Factors Ergon Soc Annu Meet 2002;46:1594-1598.

88. Vater C, Gray R, Holcombe AO. A Critical Systematic Review of The Neurotracker Perceptual-Cognitive Training tool. Psychon Bull Rev; Available at: http://doi.org/10.5281/zenodo.4544265

89. Tullo D, Guy J, Faubert J, et al. Training with A Three-Dimensional Multiple Object-Tracking (3d-Mot) Paradigm Improves Attention in Students with A Neurodevelopmental Condition: A Randomized Controlled Trial. Dev Sci 2018;21:e12670.

90. Musteata S, Yoshida K, Baranzini D, et al. Perceptual-Cognitive Training Can Improve Cognition in Older Adults with Subjective Cognitive Decline. ASMHS 2019;3:1–15.

91. Corbin-Berrigan LA, Faubert J, Gagnon I. Neurotracker As A Potential Mean of Active Rehabilitation in Children with Atypical Mild Traumatic Brain Injury Recovery: A Pilot Safety Study. Transl Sports Med 2020;3:235–42.

92. Corbin-Berrigan LA, Kowalski K, Faubert J, et al. Could Neurotracker Be Used As A Clinical Marker of Recovery Following Pediatric Mild Traumatic Brain Injury? An Exploratory Study. Brain Inj 2020;34:385–9.

93. Corbin-Berrigan LA, Kowalski K, Faubert J, et al. Three-Dimensional Multiple Object Tracking in the Pediatric Population: The Neurotracker and Its Promising Role in The Management of Mild Traumatic Brain Injury. Neuroreport 2018;29:559–63.
94. Faubert J. Professional Athletes Have Extraordinary Skills for Rapidly Learning Complex and Neutral Dynamic Visual Scenes. Sci Rep 2013;3:1–3.
95. Smith TQ, Mitroff SR. Stroboscopic Training Enhances Anticipatory Timing. Int J Exerc Sci 2012;5:344–53.
96. Appelbaum LG, Cain MS, Schroeder JE, et al. Stroboscopic Visual Training Improves Information Encoding in Short-Term Memory. Atten Percept Psychophys 2012;74:1681–91.
97. Bennett SJ, Hayes SJ, Uji M. Stroboscopic Vision When Interacting with Multiple Moving Objects: Perturbation Is Not the Same as Elimination. Front Psychol 2018;9:1290.
98. Ballester R, Huertas F, Uji M, et al. Stroboscopic Vision and Sustained Attention during Coincidence-Anticipation. Sci Rep 2017;7:1–7.
99. Fransen J, Lovell TWJ, Bennett KJM, et al. The Influence of Restricted Visual Feedback on Dribbling Performance in Youth Soccer Players. Motor Control 2017;21:158–67.
100. Appelbaum LG, Schroeder JE, Cain MS, et al. Improved Visual Cognition through Stroboscopic Training. Front Psychol 2011;2:1–13.
101. Wilkins L, Gray R. Effects of Stroboscopic Visual Training on Visual Attention, Motion Perception, and Catching Performance. Percept Mot Skills 2015;121:57–79.
102. Appelbaum LG, Lu Y, Khanna R, et al. The Effects of Sports Vision Training on Sensorimotor Abilities in Collegiate Softball Athletes. Athl. Train. Sports Health Care 2016;8:154–63.
103. Clark JF, Ellis JK, Bench J, et al. High-Performance Vision Training Improves Batting Statistics for University of Cincinnati Baseball Players. PLoS One 2012;7:e29109.
104. Mitroff SR, Friesen P, Bennett D, et al. Enhancing Ice Hockey Skills Through Stroboscopic Visual Training: A Pilot Study. Athl. Train. Sports Health Care 2013;5:261–4.
105. Wilkins L, Appelbaum LG. An Early Review of Stroboscopic Visual Training: Insights, Challenges and Accomplishments to Guide Future Studies. Int Rev Sport Exerc Psychol 2019:1–16.
106. Ellison PH, Jones C, Sparks SA, et al. The Effect of Stroboscopic Visual Training on Eye–Hand Coordination. Sport Sci Health 2020;7:1–10.
107. Reigal RE, Barrero S, Martín I, et al. Relationships during Reaction Time, Selective Attention, Physical Activity, and Physical Fitness in Children. Front Psychol 2019;10:2278.
108. Florkiewicz B, Fogtman S, Lesiakowski P, et al. The Effect of Visual Perception Training on Sensorimotor Function in Handball Players. Antropomotoryka. Journal of Kinesiology and Exercise Sciences 2015:25–32.
109. Millikan N, Grooms DR, Hoffman B, et al. The Development and Reliability of 4 Clinical Neurocognitive Single-Leg Hop Tests: Implications for Return to Activity Decision-Making. J Sport Rehabil 2019;28:536–44.
110. Zwierko T, Florkiewicz B, Fogtman S, et al. The Ability to Maintain Attention during Visuomotor Task Performance in Handball Players and Non-Athletes. Cent. Eur. J. Sport Sci. Med. (Online) 2014;7:99–106.
111. Serrien B, Tassignon B, Verschueren J, et al. Short-Term Effects of Differential Learning and Contextual Interference in A Goalkeeper-Like Task: Visuomotor Response Time and Motor Control. Eur J Sport Sci 2019:1–11.
112. Laessoe U, Grarup B, Bangshaab J. The Use of Cognitive Cues for Anticipatory Strategies in A Dynamic Postural Control Task - Validation of A Novel Approach to Dual-Task Testing. PLoS One 2016;11:e0157421.
113. van Cutsem J, de Pauw K, Vandervaeren C, et al. Mental Fatigue Impairs Visuomotor Response Time in Badminton Players and Controls. Psychol Sport Exerc 2019;45:101579.

114. Vater C, Klostermann A, Kredel R, et al. The Role of Peripheral Vision in Sports and Everyday Life. In: Williams AM, Jackson RC, eds. Anticipation and decision making in sport. Abingdon, Oxon, New York, NY: Routledge; 2019:79–98.

115. Wilke J, Vogel O, Ungricht S. Can We Measure Perceptual-Cognitive Function during Athletic Movement? A Framework for and Reliability of a Sports-Related Testing Battery. Phys Ther Sport 2020;43:120–6.

116. Snyder N, Cinelli M. Comparing Balance Control during Soccer Players and Non-Athletes during A Dynamic Lower Limb Reaching Task. Res Q Exerc Sport 2020;91:166–71.

117. Schuhfried G. Vienna Test System: Psychological assessment. Moedling: Schuhfried.; 2013.

118. Kunrath CA, Nakamura FY, Roca A, et al. How Does Mental Fatigue Affect Soccer Performance during Small-Sided Games? A Cognitive, Tactical and Physical Approach. J Sports Sci 2020:1–11.

119. Zwierko T. Differences in Peripheral Perception during Athletes and Nonathletes. J Hum Kinet 2007;19:53–62.

120. Schumacher N, Schmidt M, Reer R, et al. Peripheral Vision Tests in Sports: Training Effects and Reliability of Peripheral Perception Test. Int J Environ Res Public Health 2019;16.

121. Zwierko T, Osinski W, Lubiński W, et al. Speed of Visual Sensorimotor Processes and Conductivity of Visual Pathway in Volleyball Players. J Hum Kinet 2010;23:21–7.

122. Jiménez-Pavón D, Romeo J, Cervantes-Borunda M, et al. Effects of A Running Bout in The Heat on Cognitive Performance. J Exerc Sci Fit 2011;9:58–64.

123. Zwierko T, Głowacki T, Osiński W. The Effect of Specific Anaerobic Exercises on Peripheral Perception in Handball Players. Kinesiol. Slov. 2008;14:68–76.

124. Poliszczuk T, Poliszczuk D, Dąbrowska-Perzyna A, et al. Asymmetry of Complex Reaction Time in Female Épée Fencers of Different Sports Classes. Polish J. Sport Tour. 2013;20:25–9.

125. Schumacher N, Reer R, Braumann K-M. On-Field Perceptual-Cognitive Training Improves Peripheral Reaction in Soccer: A Controlled Trial. Front Psychol 2020;11:1948.

126. Kasten E, Strasburger H, Sabel BA. Programs for Diagnosis and Therapy of Visual Field Deficits in Vision Rehabilitation. Spat Vis 1997;10:499–503.

127. Poggel DA, Treutwein B, Calmanti C, et al. The Tölz Temporal Topography Study: Mapping the Visual Field Across The Life Span. Part I: The Topography of Light Detection and Temporal-Information Processing. Atten Percept Psychophys 2012;74:1114–32.

128. Williams AM, Davids K. Assessing Cue Usage in Performance Contexts. A Comparison during Eye-Movement and Concurrent Verbal Report Methods. Behav Res Methods Instrum Comput 1997;29:364–75.

129. Hausegger T, Vater C, Hossner EJ. Peripheral Vision in Martial Arts Experts: The Cost-Dependent Anchoring of Gaze. J Sport Exerc Psychol 2019;41:137–46.

130. Williams AM, Elliott D. Anxiety, Expertise, and Visual Search Strategy in Karate. J Sport Exerc Psychol 1999;21:362–75.

131. Henderson JM. Human Gaze Control during Real-World Scene Perception. Trends Cognit Sci 2003;7:498–504.

132. Drew T, McCollough AW, Horowitz TS, et al. Attentional Enhancement during Multiple-Object Tracking. Psychon Bull Rev 2009;16:411–7.

133. Latzman RD, Markon KE. The Factor Structure and Age-Related Factorial Invariance of the Delis-Kaplan Executive Function System (D-KEFS). Assessment 2010;17:172–84.

134. Anderson L, Cross A, Wynthein D, et al. Effects of Dynavision Training as a Preparatory Intervention Status Postcerebrovascular Accident: A Case Report. Occup Ther Health Care 2011;25:270–82.

135. Bello ML, Walker AJ, McFadden BA, et al. The Effects of Teacrine® and Caffeine on Endurance and Cognitive Performance during A Simulated Match in High-Level Soccer Players. J Int Soc Sports Nutr 2019;16:1–10.

136. Bigsby K, Mangine RE, Clark JF, et al. Effects of Postural Control Manipulation on Visuomotor Training Performance: Comparative Data in Healthy Athletes. Int J Sports Phys Ther 2014;9:436–46.

137. Bixenmann B, Bigsby K, Hasselfeld KA, et al. Retinal and Balance Changes Based on Concussion History: A Study of Division 1 Football Players. Int J Phys Med Rehabil 2014:234:1–6.

138. Bruce S, Fagan S, Cummins C, et al. Effect of Therapeutic Tape on Upper Extremity Reaction Time. The Sport Journal 2017:1–10.

139. Carrick FR, Clark JF, Pagnacco G, et al. Head-Eye Vestibular Motion Therapy Affects the Mental and Physical Health of Severe Chronic Postconcussion Patients. Front. Neurol. 2017;8:1–16.

140. Church DD, Hoffman JR, LaMonica MB, et al. The Effect of an Acute Ingestion of Turkish Coffee on Reaction Time and Time Trial Performance. J Int Soc Sports Nutr 2015;12:1–11.

141. Cross, A. K., Brockevelt, B. L., Kruisselbrink, A. R., Triplett, A. S., & Flett, J. M. The Effectiveness of Dynavision Training to Improve Visual Motor Skills of Collegiate Athletes: A Pilot Study. Gazz Med Ital 2013;172:627–34.

142. Dawes JJ, Campbell BI, Ocker LB, et al. The effects of a pre-workout energy drink on measures of physical performance. Int J Phys Educ Fit Sports 2014;3:122–31.

143. Feldhacker DR, Molitor WL. Pilot Study of an Occupational Therapy Dynavision D2 Protocol for Enhancement of Visual Performance Among Collegiate Athletes. Ann. Int. Occup. Ther. 2019;2:69–78.

144. Gonzalez AM, Hoffman JR, Wells AJ, et al. Effects of Time-Release Caffeine Containing Supplement on Metabolic Rate, Glycerol Concentration and Performance. J Sports Sci Med 2015;14:322–32.

145. Jajtner AR, Hoffman JR, Scanlon TC, et al. Performance and Muscle Architecture Comparisons during Starters and Nonstarters in National Collegiate Athletic Association Division I Women's Soccer. J. Strength Cond. Res. 2013;27:2355–65.

146. Mangine GT, Hoffman JR, Wells AJ, et al. Visual Tracking Speed Is Related to Basketball-Specific Measures of Performance in NBA Players. J. Strength Cond. Res. 2014;28:2406–14.

147. Picha K, Quintana C, Glueck A, et al. Reliability of 5 Novel Reaction Time and Cognitive Load Protocols. J Sport Rehabil 2018;27:1–4.

148. Pruna GJ, Hoffman JR, McCormack WP, et al. Effect of Acute L-Alanyl-L-Glutamine and Electrolyte Ingestion on Cognitive Function and Reaction Time Following Endurance Exercise. Eur J Sport Sci 2016;16:72–9.

149. Purpura M, Rathmacher JA, Sharp MH, et al. Oral Adenosine-5'-triphosphate (ATP) Administration Increases Postexercise ATP Levels, Muscle Excitability, and Athletic Performance Following a Repeated Sprint Bout. J Am Coll Nutr 2017;36:177–83.

150. Razon S, Lebeau J-C, Basevitch I, et al. Effects of Acute Exercise on Executive Functioning: Testing The Moderators. Int J Sport Exerc Psychol 2019;17:303–20.

151. Schwab S, Memmert D. The Impact of A Sports Vision Training Program in Youth Field Hockey Players. J Sports Sci Med 2012;11:624–31.

152. Stone SA, Baker J, Olsen R, et al. Visual Field Advantage: Redefined by Training? Front Psychol 2018;9:2764.

153. Wilkerson GB, Simpson KA, Clark RA. Assessment and Training of Visuomotor Reaction Time for Football Injury Prevention. J Sport Rehabil 2017;26:26–34.

154. Assed MM, De Carvalho MKHV, Rocca CCdA, et al. Memory Training and Benefits for Quality of Life in The Elderly: A Case Report. Dement Neuropsychol 2016;10:152–5.

155. Chamoun M, Huppé-Gourgues F, Legault I, et al. Cholinergic Potentiation Improves Perceptual-Cognitive Training of Healthy Young Adults in Three Dimensional Multiple Object Tracking. Front Hum Neurosci 2017;11:128.

156. Chermann J-F, Romeas T, Marty F, et al. Perceptual-Cognitive Three-Dimensional Multiple-Object Tracking Task Can Help The Monitoring of Sport-Related Concussion. BMJ Open Sport Exerc Med 2018;4:e000384.

157. Fabri TL, Wilson KE, Holland N, et al. Using a Dual-Task Protocol to Investigate Motor and Cognitive Performance in Healthy Children and Youth. Gait & Posture 2017;54:154–9.

158. Fragala MS, Beyer KS, Jajtner AR, et al. Resistance Exercise May Improve Spatial Awareness and Visual Reaction in Older Adults. J Strength Cond Res 2014;28:79–87.

159. Harenberg S, McCaffrey R, Butz M, et al. Can Multiple Object Tracking Predict Laparoscopic Surgical Skills? J Surg Educ 2016;73:386–90.

160. Harris DJ, Wilson MR, Crowe EM, et al. Examining the Roles of Working Memory and Visual Attention in Multiple Object Tracking Expertise. Cogn Process 2020;21:209-22.

161. Legault I, Faubert J. Perceptual-Cognitive Training Improves Biological Motion Perception: Evidence for Transferability of Training in Healthy Aging. Neuroreport 2012;23:469–73.

162. Legault I, Allard R, Faubert J. Healthy Older Observers Show Equivalent Perceptual-Cognitive Training Benefits to Young Adults for Multiple Object Tracking. Front Psychol 2013;4:1–7.

163. Lysenko-Martin MR, Hutton CP, Sparks T, et al. Multiple Object Tracking Scores Predict Post-Concussion Status Years after Mild Traumatic Brain Injury. J Neurotrauma 2020; 37:1777–87.

164. Mejane J, Faubert J, Romeas T, et al. The Combined Impact of A Perceptual–Cognitive Task and Neuromuscular Fatigue on Knee Biomechanics during Landing. The Knee 2019;26:52–60.

165. Michaels J, Chaumillon R, Nguyen-Tri D, et al. Driving Simulator Scenarios and Measures to Faithfully Evaluate Risky Driving Behavior: A Comparative Study of Different Driver Age Groups. PLoS One 2017;12:e0185909.

166. Moen F, Hrozanova M, Stiles T. The Effects of Perceptual-Cognitive Training with Neurotracker on Executive Brain Functions Among Elite Athletes. Cogent Psychology 2018;5:1–13.

167. Plourde M, Corbeil ME, Faubert J. Effect of Age and Stereopsis on A Multiple-Object Tracking Task. PLoS One 2017;12:e0188373.

168. Romeas T, Chaumillon R, Labbé D, et al. Combining 3D-MOT with Sport Decision-Making for Perceptual-Cognitive Training in Virtual Reality. Percept Mot Skills 2019;126:922–48.

169. Tullo D, Faubert J, Bertone A. The Characterization of Attention Resource Capacity and Its Relationship with Fluid Reasoning Intelligence: A Multiple Object Tracking Study. Intelligence 2018;69:158–68.

170. Vartanian O, Coady L, Blackler K. 3D Multiple Object Tracking Boosts Working Memory Span: Implications for Cognitive Training in Military Populations. Military Psychology 2016;28:353–60.

171. Kim KM, Kim JS, Grooms DR. Stroboscopic Vision to Induce Sensory Reweighting during Postural Control. J Sport Rehabil 2017;26:1–5.

172. Čoh M. Reactive (Pre-Planned) and Non-Reactive (Non-Planned) Agility in Diagnosis of Athletes. Physical Education and Sport Through the Centuries 2019;6:95–106.

173. Rauter S, Coh M, Vodicar J, et al. Analysis of Reactive Agility and Change-Of-Direction Speed during Soccer Players and Physical Education Students. Hum. Mov. 2018;2018:68–74.

174. Shelly Z, Stewart E, Fonville T, et al. Helmet Prototype Response Time Assessment Using NCAA Division 1 Collegiate Football Athletes. IJKSS 2019;7:53–65.

Figure Legends

Figure 1. A flow chart indicating the number of studies included in the four stages from identification of relevant studies to their eventual inclusion. Boxes on the right indicate the reasons for excluding papers from the next stage of analysis.

Appendix

Search example for ScienceDirect:

https://www.sciencedirect.com/search?qs=Sport%20And%20%22Vienna%20Test%20System%22&articleTypes=FLA

TABLE 1. Overview of what information was extracted for the five devices included in the review

			General methods criteria							**Device-specific criteria**						
Device	**Authors**	**Year**	**Group of participants**	**n**	**Eye-Tracking**	**Standard position**	**Study design**	**Instruction to use PV**	**Transfer test**							
Dynavision D2	x	x	x	x	x	x		x		Secondary task	Test mode	Familiarization trials	Target light duration	Subset of rings	Interval between digits	Digit duration
CogniSense Neurotracker	x	x	x	x	x	x	x	x	x	Number of targets						
Nike Sparq Vapor Strobe	x	x	x	x			x		x	Training/ test duration	Task	Opaque interval				
FitLight Trainer	x	x	x	x	x	x		x		Number of targets	Interval between target lights (s)	Number of series and reactions	Motor response	Visual field (horizontal)		
Vienna Test System	x	x	x	x	x	x	x	x		Foveal task performance	FOV (°)					

Abbreviations: PV = peripheral vision; FOV = field of view; x = information extracted.

TABLE 2. Characteristics of studies on the Dynavision D2

Study	Group of participants	n	Eye-tracking	Secondary task	Interval between digits (s)	Digit duration (s)	Instructed to use PV	Standard position	Test mode	Familiarization trials	Target light duration (s)	Subset of rings
Anderson, et al. (2011)[134]	67-year old woman	1	no	no	-	-	n.d.	n.d.	A, B	2 × 60s	3	-
Bello, et al. (2019)[135]	high-level male and female soccer players	24	no	yes	3	1	n.d.	n.d.	A, B	3 × 60s	n.d.	-
Bigsby, et al. (2014)[136]	Division I college football team members	105	no	no	-	-	n.d.	yes	A,C	1 trial	n.d.	-
Bixenmann, et al. (2014)[137]	Division I college football players	107	no	yes (balance)	-	-	n.d.	yes	A,C	n.d.	n.d.	-
Bruce, et al. (2017)[138]	healthy, physically active, college-aged volunteers	56	no	no	-	-	n.d.	yes	A,C	1 × 60s	n.d.	-
Carrick, et al. (2017)[139]	subjects with sports concussions	70	no	no	-	-	n.d.	n.d.	n.d.	n.d.	n.d.	-
Church, et al. (2015)[140]	recreationally active individuals	20	no	yes	5	n.d.	n.d.	yes	A,B,C	n.d.	1	-
Clark, et al. (2012)[103]	Division I college baseball team	n.d.	no	no	-	-	n.d.	n.d.	A	n.d.	n.d.	-
Clark, et al. (2015)[70]	baseball, football, and volunteer subjects	101	no	yes	8	1	yes	yes	A	1 × 60s	n.d.	-
Clark, et al. (2015)[65]	University of Cincinnati football team	n.d.	no	yes (in training)	n.d.	n.d.	n.d.	yes	A, C	2 × 60s	n.d.	-
Clark, et al. (2017)[72]	college athletes, college students, and concussion patients	53	no	no	-	-	yes	n.d.	C	n.d.	n.d.	-
Cross, et al. (2013)[141]*	female collegiate volleyball players	7							B			
Dawes, et al. (2014)[142]	healthy males	41	no	no	-	-	n.d.	yes	C	n.d.	n.d.	-
Feldhacker, et al.(2019)[143]	Division I women softball team	21	no	yes (in training)	n.d.	n.d.	n.d.	n.d.	A,C (test), B,C (train)	3 × 60s	n.d.	-
Fragala, et al. (2014)[76]	adults (age >60 years)	25	no	no	-	-	n.d.	n.d.	A,C	n.d.	n.d.	-
Gonzalez, et al. (2015)[144]	male regular caffeine consumers	10	no	yes	5	n.d.	n.d.	yes	A, B, C	n.d.	1	-
Hoffmann, et al. (2012)[66]	NCAA Division I Basketball	10	no	no	-	-	yes	yes	C	n.d.	n.d.	-
Jajtner, et al. (2013)[145]	players from women’s soccer team	28	no	no	-	-	n.d.	yes	C	n.d.	n.d.	-
Kauffman, et al. (2015)[69]	female Division I athletes from multiple sports	54	no	no	-	-	yes	yes	A	n.d.	n.d.	-

Klavora, et al. (1994)[63]	university students	117	no	yes	5	1	yes	yes	B	n.d.	0.5, 1	-
Klavora, et al. (1995)[62]	university students	102	no	yes	5	1	yes	yes	A,B	yes	0.5,1	-
Mangine, et al. (2014)[146]	professional basketball players	12	no	no	-	-	n.d.	yes	A, C	n.d.	n.d.	-
Miller, et al. (2019)[67]	Division I NCAA football players	25	no	no	-	-	yes	yes	A	n.d.	n.d.	3,4,5
Picha, et al. (2018)[147]	healthy adults	30	no	yes (math and reading)	n.d.	n.d.	yes	yes	A, B	3 × 60s (before session 1)	0.75	-
Pruna, et al. (2016)[148]	male endurance athletes	12	no	yes	5	n.d.	yes	yes	A,B,C	n.d.	1	-
Purpura, et al. (2017)[149]	healthy males	30	no	no	-	-	n.d.	n.d.	C	n.d.	n.d.	-
Razon, et al. (2016)[150]	healthy male and female	83	no	yes (math)	n.d.	n.d.	n.d.	yes	B	1 × 30s	1	1,2,3
Schwab & Memmert (2012)[151]	field hockey players	34	no	n.d.	n.d.	n.d.	n.d.	n.d.	C	n.d.	n.d.	-
Stone, et al. (2018)[152]	young adults	40	no	no	-	-	n.d.	yes	A	2 × 60s	n.d.	1,2,3,4
Wells, et al. (2014)[68]	young adults	42	no	yes	5	0.75	yes	yes	A, B, C	3 × 30s	1	-
Wilkerson, et al. (2017)[153]	college football players	42	no	yes (numbers, words, sentences)	-	-	n.d.	yes	A, B	3 × 30s	-	-

Abbreviations: PV = peripheral vision; n.f. = not found; n.d. = not defined; Note: No full text was available for references marked with *. The information provided in the table was taken from a previous review.[61]

TABLE 3. Characteristics of studies on the Neurotracker

Study	Group of participants	n	Eye-Tracking	Instructed to use PV/ fixate straight	Standardized position / Size of virtual cube in visual field	Nr of targets	Study design	Sports-transfer task
Assed et al. (2016)[154]	women	1	no	no	n.d.	1 to 3	intervention	no
Chamoun et al. (2017)[155]	healthy young adults	17	no	yes	177 cm away from central wall of cave	4	between-group	no
Chermann et al. (2018)[156]	rugby players with and without concussion	59	no	no	45°	4	intervention	no
Corbin-Berrigan et al. (2018)[93]	mTBI patients and healthy controls	34	no	no	160 cm away from a 60” TV	4	intervention	no
Corbin-Berrigan et al. (2020)[92]	clinically recovered mTBI patients and healthy controls	20	no	no	n.d.	4	intervention	no
Corbin-Berrigan et al. (2020)[91]	children with post-concussion syndrome	9	no	no	60” screen	4	intervention	no
Fabri et al. (2017)[157]	healthy children and youth	106	no	no	n.d.	3	within- vs. between-group	no
Faubert et al. (2013)[94]	professional athletes (soccer, hockey, rugby), elite amateurs and non-athletes	308	no	no	46°	4	between-group	no
Fleddermann et al. (2019)[85]	elite volleyball experts	43	no	no	46°	4	intervention	yes
Fragala et al. (2014)[158]	older adults	25	no	no	n.d.	n.d.	intervention	no
Harenberg et al. (2016)[159]	students	29	no	no	152 cm away from a 65” TV	4	correlation	no
Harris et al. (2020)[86]	students	84	no	no	48°	4	intervention	yes
Harris et al. (2020)[160]	students	36	no	no	48°	4	intervention	no
Legault & Faubert (2012)[161]	older adults	41	no	no	42°	4	intervention	no
Legault et al. (2013)[162]	younger and older adults	40	no	yes	42°	3 or 4	between-group and intervention	no
Lysenko-Martin et al. (2020)[163]	participants with concussion histories	457	no	yes	160 cm away from a 52” TV	4	correlation	no
Mangine et al. (2014)[146]	NBA players	12	no	no	46°	4	correlation	no
Mejane et al. (2019)[164]	female recreational athletes	19	no	no	130 cm from screen	3	within-group	no
Michaels et al. (2017)[165]	adults (licensed drivers)	115	no	no	n.d.	4	correlation	no
Moen et al. (2018)[166]	athletes from various sports	60	no	no	n.d.	2 to 4	intervention	no
Musteata et al. (2019)[90]	older adults	47	no	no	n.d.	4	intervention	no
Parsons et al. (2014)[75]	students	20	no	no	cube size 8 × 8 feet	4	intervention	no
Plourde et al. (2017)[167]	children, adults, and older adults	60	no	no	40cm from 10 tablet	3	between-group	no
Romeas et al. (2016)[84]	university-level soccer players	19	no	yes	HMD	4	intervention	yes
Romeas et al. (2019)[168]	university badminton athletes	71	no	no	46°	4	intervention	no
Tullo et al. (2018)[89]	students with neurodevelopmental condition	129	no	no	5 feet away from 50” TV	3	intervention	no
Tullo et al. (2018)[169]	adults	70	no	no	HMD, 46°	1 to 4	correlation	no
Vartanian et al. (2016)[170]	army members	41	no	no	5.5 feet away from 65” TV	4	intervention	no

Abbreviations: PV = peripheral vision; n.f. = not found; n.d. = not defined; mTBI = mild traumatic brain injury;

TABLE 4. Characteristics of studies on the Nike SPARQ Vapor Strobe

Author(s)	Group of participants	n	Study design	Opaque interval (ms)	Training/ test duration	Task	Transfer test
Appelbaum et al. (2011)[100]	students, athletic team members	157	intervention	level 1-6	frisbee: 6 sessions football: 9-10 sessions	frisbee: passing and throwing drills in stationary and running situations; football: warm-up and agility drills, with variability in timing (10-30 min)	UFOV, MOT
Appelbaum et al. (2012)[96]	students, member of athletic teams	84	intervention	level 1-6	15-45	in-lab: turn-and-catch drills (27 min) soccer: passing and dribbling drills (15-45 min); basketball: warm-up and agility drills	partial-report task (identify letter in ring of letters around a fixation point)
Appelbaum et al. (2016)[102]	college softball athletes	25	intervention	start level 3: increased/ decreased over time or additional drill	22 times, 5-10 minutes	strobe softball and strobe batting (task: batting against a machine for 3-5 min)	Nike Sensory Station (9 tasks: Visual Clarity, Contrast Sensitivity, Depth Perception, Near-Far Quickness, Target Capture, Perception Scan, Eye-Hand Coordination, Go/No-Go, and Response Time)
Ballester et al. (2017)[98]	male undergraduate students	20	within-group	level 3 (150ms)	120 trials	coincidence-anticipation task (press button when target reaches final position on a 3-m LED track)	Psychomotor vigilance task (PVT)
Bennett et al. (2018)[97]	young adults	18	between-group, intervention	level 2, 4, 6	96 trials	MOT and MOA (move white cursor to red target whilst avoiding the green objects); secondary audio-cue detection task	no
Clark et al. (2012)[103]	professional baseball players	n.d.	intervention	n.d.	2 sessions per week in season	baseball batting	no
Clark et al. (2015)[70]	football players	101	intervention	start: speed 1 or 2; end: speed 4-6	n.d.	throw balls between subjects	no
Ellison et al.(2020)[106]	male participants	62	intervention	level 3: 150ms	7-8min	Sport Vision Trainer (eye-hand coordination; task: touch light as it illuminates)	visual search task
Fransen et al. (2017)[99]	youth soccer players	189	within-between-group	level 3 (150ms), level 7 (650ms)	1 trial	soccer dribble test	no
Kim et al. (2017)[171]	healthy subjects	18	within-group	100ms	1 trial, 10s	single-leg stance (balance task)	no
Mitroff et al. (2013)[104]	NHL ice hockey players	11	intervention	level 1-6	10 min per day for 16 days	normal training (e.g., passing, skating on ice and during balance or conditioning drills)	Ice-hockey-specific and position-specific task (forwards: goal scoring; defensemen: long passes)

Smith and Mitroff (2012)[95]	university members	30	(short) inter-vention	level 3 (150ms)	5 blocks with 10 trials	anticipatory timing task (Bassin Anticipation Timer with 200 red LEDs on a 4m track; task: press button when signal reaches end of track)	Anticipatory timing task
Wilkins & Gray (2015)[101]	athletes	30	inter-vention	constant: 40ms; variable: increased from 40 to 120ms)	8 sessions × 20 min	four simple tennis-ball catching drills (wall-ball catch, the front catch, the turn and catch, and the power ball drop)	The Team Sports UFOV test (single- and dual-task; running direction of central player and/or position of peripheral player), Motion in Depth Sensitivity test (MIDS; task: decide which flow field has greater movement speed)

Abbreviations: n.f. = not found; n.d. = not defined; mTBI = mild traumatic brain injury; MOT = Multiple Object Tracking; MOA = Multiple Object Avoidance; UFOV = useful field of view

TABLE 5. Characteristics of studies on the FitLight system

Author(s)	Group of participants	n	Eye-tracking	Instruction to use PV	Standardized position	Visual field (horizontal)	Number of targets	Interval between target lights (s)	Number of series and reactions	Motor response
Čoh (2019)[172]	student athletes	76	no	no	n.d.	n.d.	7	random	n.d.	full body (sprints and jumps)
Florkiewicz et al. (2015)[108]	university handball players and non-athletic students	28	no	no	yes	180°	8	random	test 1: 2 × 22; test 2: 30 s	test 1: dominant hand test 2: full body
Laessoe et al. (2016)[112]	elderly and young people	45	no	no	yes	approx. 180°	8	0.5	6 × 25	full-body reaching movement
Millikan et al. (2019)[109]	students	22	no	yes	yes	200-220°	10	-	3 successful hops	jump with one foot ("peripheral reaction hop")
Rauter et al. (2018)[173]	young soccer players and students	94	no	no	yes	200-220°	7	random	4 × 6	full-body
Reigal et al. (2019)[107]	children (10-12 years)	119	no	no	yes	180°	8	random	2 × 60	dominant hand
Serrien et al. (2019)[111]	students and research assistants	16	no	no	no	approx. 170°	6	2.5	4 × 15	arm movements
Shelly et al. (2019)[174]	football student-athletes	18	no	yes	yes	180°	10	random	3 × 50	arm movements
Snyder and Cinelli (2020)[116]	soccer players and non-athlete controls	43	no	no	yes	120°	5	random	12 × 6	balance task and reaching movement with both legs
Van Cutsem et al. (2019)[113]	badminton players	20	no	no	yes	approx. 85°	8	3, 4, 5 or 6	1 × 64	full-body
Wilke et al. (2020)[115]	healthy, active individuals	13	no	no	yes	up to 360°	8	random	6 tests with 20-60 trials	tests with hand and full-body movements
Zwierko et al. (2014)[110]	expert handball players and non-athletes	24	no	no	yes	approx. 170°	8	0.1 - 3.0	10 × 22	dominant hand

Abbreviations: n.f. = not found; n.d. = not defined; Note: If the visual field (in which stimuli were positioned) was not specified by the authors, it was estimated based on the description or figure for the experimental setup.

TABLE 6. Characteristics of studies on the Vienna Test System

Author(s)	**Group of participants**	**n**	**Study design**	**Eye tracking**	**Instructed to use PV**	**Standard position**	**Foveal task performance (tracking deviation in px)**	**Reported FOV (°)**
Jimenez-Pavon et al. (2011)[122]	physically active men	22	within-group	no	no	n.d.	no	pre: 175 ± 9 post: 171 ± 8
Kunrath et al. (2020)[118]	university soccer players	18	within-group (Stroop task)	no	no	n.d.	pre: 5.46 post: 5.44	pre: 189.9 ± 12.03 post: 181.6 ± 7.69
Poliszczuk et al. (2013)[124]	female basketball players	17	single test	no	no	n.d.	no	approx. 175
Schumacher et al. (2019)[120]	male athletes	21	test-retest reliability	no	no	sitting position; 30-60 cm distance to screen	T0: 8.23 T1: 8.29	T0: 184.34 ± 6.98 T1: 183.09 ± 6.80
Zwierko et al. (2007)[119]	handball players	32	between-group	no	no	n.d.	athletes: 11.11 ± 1.09 nonathletes: 13.87 ± 2.10	athletes: 170.95 ± 9.15; nonathletes: 173.76 ± 3.82
Zwierko et al. (2008)[123]	handball players	18	within-group	no	no	n.d.	before effort: 11.43 ± 1.44 after effort: 11.44 ± 1.76	before effort: 167.46 ± 12.83 after effort: 173.46 ± 7.72
Zwierko et al. (2010)[121]	volleyball players and non-athletic subjects	24	between- group	no	no	n.d.	no	no

Abbreviations: n.f. = not found; n.d. = not defined