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Association Between Visuomotor Skills and the Effects of Stroboscopic Vision on Depth Jump Performance

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ASSOCIATION BETWEEN VISUOMOTOR SKILLS AND THE EFFECTS OF STROBOSCOPIC VISION ON DEPTH JUMP PERFORMANCE

by

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ABSTRACT

The reactive strength index (RSI) is a popularized method of evaluating depth jump performance. Performance in anticipation of ground impact is influenced by the proprioceptive, vestibular, and visuomotor systems through multisensory integration. The contribution of vision to depth jump performance has been studied through use of stroboscopic goggles, but no study has evaluated which visuomotor skills may be a predictor for DJ performance. The purpose of this investigation was to evaluate the association between visuomotor skills and the effects of stroboscopic vision on DJ performance. Participants consisted of 9 female and 13 male college aged adults. DJ performance was evaluated using RSI via force platform data under conditions of full vision and stroboscopic vision set at a frequency of 3 Hz. Subjects completed seven visuomotor assessments, and performed 6 trials of DJ's in both the stroboscopic and full vision conditions off a 0.51m plyometric box. Main effects were evaluated for statistical significance using two-way analyses of variance (ANOVA's). Upon observation of a significant interaction, post-hoc analysis was performed using one-way repeated measures ANOVA followed with paired *t*-tests to evaluate for main effects of visual condition on trial number, as well as visual condition on RSI scores. Significant interaction was observed between stroboscopic vision and RSI scores with a reduction of 8.5%. The main contributor to this change was an 8.3% reduction in rebound jump height. There was no linear relationship observed between visuomotor performance and DJ performance. Further investigation is required at variable frequency stroboscopic vision to determine visuomotor performance data as a predictor for in sport performance.

Introduction

Plyometrics are movements characterized by the production of high rates of force development from utilization of the strength-shortening cycle (SSC) action of skeletal muscle (Komi, 2008). The SSC is a natural skeletal muscle action that involves a rapid eccentric muscle action followed by an increase in contractile velocity during a subsequent concentric muscle action (Komi, 2008). High levels of performance in plyometric movements require efficient utilization of the SSC. With plyometrics being associated with quick movement, there is less time for information processing and decision making by the central nervous system (CNS). Therefore, effective utilization of the SSC is dependent, in part, on anticipatory feedforward control and involuntary feedback reflex loops.

The depth jump (DJ) is a specific plyometric movement that is commonly used to monitor injury rehabilitation progress, injury risk, and physical agility (Chu, 1998). Performing a DJ requires that a person self-initiates a drop from a raised platform down to a lower landing surface. Upon landing, the DJ involves a rapid absorption of landing impact ground reaction forces (GRF) followed immediately by the performance of a maximal vertical jump. Researchers are able to derive a multitude of meaningful outcome measures from DJ performance. Notably, the DJ and drop landings provide researchers and practitioners with a movement paradigm for evaluating the mechanics of lower-extremity joint rotations and vertical GRF during landing impact (Leukel et al., 2012; Santello, 2005). In recent years, there has been a growing interest in using GRF data to derive the reactive strength index (RSI). The RSI is calculated by taking the ratio of DJ height to ground contact time (GCT; Montalvo et al., 2021), giving a broad metric of lower-extremity SSC ability.

When humans land from a self-initiated drop, skeletal muscle activation increases during the drop phase in anticipation of ground impact (Leukel et al., 2012; Santello, 2005). Pre-activation is believed to play an important role in successfully and safely landing from a drop by means of developing musculotendinous stiffness prior to landing impact (Leukel et al., 2012; Santello, 2005). The magnitude of stiffness developed prior to landing is task-dependent, with Leukel et al. (2012) observing greater stiffness for the DJ when compared to a simple drop landing. This finding is suggested to occur, in part, because the DJ involves feedforward prediction of the need to react upon landing in order to initiate a successful rebound jump (Leukel et al., 2012).

It is suggested that successful landings from a drop rely predominantly on feedforward motor control as there may not be adequate time for the CNS to process feedback (adaptive) and make voluntary adjustments to the motor program (Santello, 2005). However, there is some evidence that sensory stimuli may be able to facilitate adjustment of the feedforward landing program during drop landings (Santello, 2005). For instance, Leukel et al. (2012) investigated the ability of participants to switch between drop landing and depth jump techniques when presented with an auditory stimulus during the drop. Participants in the investigation were able to successfully switch movement techniques while falling in 86% of trials involving an auditory stimulus presented 170 ms before landing impact and in 61-69% of trials involving an auditory stimulus presented 110 ms before landing impact (Leukel et al., 2012). Notably, participants were unable to switch techniques when the auditory stimulus was presented 50 ms before landing impact.

The extent that CNS integration of continuous visual input, in particular, contributes to successful DJ performance is an area of study that has been gaining more attention from researchers (Herman & Barth, 2016; Kroll et al., 2020; Santello, 2005). Previous literature suggests that vision may play a role in fine-tuning the feedforward and feedback control of ballistic movements, such as jumping and landing (Bastian, 2006). For example, research on participants performing drop landings blindfolded and with full vision revealed an acute effect of visual disruption on muscle activation and onset muscle latency. Also noted was that adaptations observed over multiple trials nullified differences in performance between drop landings performed blindfolded and with full vision (Magalhães & Goroso, 2009). These findings may be evidence that the CNS uses a re-weighting strategy whereby inputs from other sensory pathways (e.g. proprioception, vestibular) are up-weighted to improve the feedforward prediction of DJ landing and takeoff mechanics when vision is absent (Kim, Kim, & Grooms, 2017), thus further supporting the role of multisensory integration in the motor control of DJ.

Interestingly, there is evidence suggesting an association between neurocognitive performance and known anterior cruciate ligament risk factors expressed during DJ (Herman & Barth, 2016). More specifically, Herman and Barth (2016) observed that recreational athletes who had lower performance on tests of reaction time and visual processing speed also performed the DJ with greater peak GRF, peak anterior tibial shear force, knee abduction moment, and knee abduction angle in contrast with athletes who displayed greater reaction time and visual processing speed abilities. Important to note is that the investigation by Herman and Barth (2016) did not include performance of the DJ under the condition of visual disruption.

It is plausible that visuomotor (VM) skills may relate to the effect of visual disruption on DJ performance. Most commonly, investigations into the role of vision in drop landings involve binary conditions, where participants perform the drop landings with either full or no vision (Magalhães & Goroso, 2009). To develop a more practical understanding of the role that vision plays in DJ, it may be of benefit to investigate the effects of controlled visual disruption in lieu of completely removing continuous visual input. Stroboscopic eyewear is a newer technology that is mobile, relatively cost sensible, and practical to employ in both lab and field-based settings. Stroboscopic eyewear provides a method for controlled visual disruption through oscillation of the lenses between defined time periods of opacity and transparency, with greater oscillation frequencies relating to a greater intensity of disruption (Kroll et al., 2020). In a sample of female collegiate volleyball athletes performing DJs from a drop height of 0.38 m, Kroll et al. (2020) observed worse DJ performance when athletes jumped under condition of stroboscopic vision versus full vision. More specifically, Kroll et al. (2020) observed that stroboscopic vision elicited greater peak GRFs and reduced RSI scores. What is uncertain from the Kroll et al. (2020) investigation is whether the effect of stroboscopic vision was influenced by participants' VM skill. Thus, the purpose of this study was to evaluate the association between VM skills and the effects of stroboscopic vision on DJ performance. Upon review of previous literature in this area, our hypothesis was that higher performance across a series of VM tests would associate with a lesser disruptive effect on RSI scores resulting from DJs being performed under condition of stroboscopic vision.

Methods

Participants

Twenty-two young male and female adults volunteered to participate in this study (Table 1). To be eligible, participants: (a) had to be between 18 and 35 years of age and (b) self-report as physically active such that they engage in a minimum of 90 minutes per week of moderate to vigorous intensity exercise as part of their normal leisure time. The sample size was selectedParticipants' physical activity routine must have included jumping, running, and/or sprinting movements. Participants were excluded from the study if: (a) they reported current physical discomfort or an injury that affects their ability to jump, (b) reported having a surgical intervention on the lower limbs or trunk in the prior 2 years, (c) reported having sustained an ACL injury in the past, (d) reported having had corrective eye surgery in the past year, (e) reported having been diagnosed with a visual impairment that cannot be corrected by refraction (e.g. contacts/glasses), (f) reported a history of concussion or seizure, (g) exceed a body weight of 220lb (99.8 kg). Participants were required to provide written consent on an informed consent document approved by the University Institutional Review Board. One female subjects' data were excluded due to a previously existing injury.

Table 1. Participant characteristics.

Sex	n	Age (years)	Height (cm)	Body Mass (kg)
Female	9	21.7 (1.7)	166.5 (4.1)	62.8 (6.2)
Male	13	23 (1.6)	180.5 (7.5)	81.3 (7.9)

Data are reported as mean (SD).

Procedures

All participants were required to attend two separate testing sessions in a Human Performance laboratory. A gap of 48 hours was provided between testing sessions to allow for adequate recovery time. Participants were asked to refrain from participating in vigorous exercise (e.g. resistance training) from 48 hours prior to the first visit through the completion of the study procedures. Each session was held at the same time of day to negate the effect of time of day on visuomotor task performance.

During the first visit, participants underwent a familiarization of study procedures. Participants first completed the following 7 pre-programmed visuomotor assessments on a tablet computer (Senaptec LLC, Beaverton, OR, USA): visual clarity, contrast sensitivity, depth perception, near-far quickness, perception span, multiple object tracking, and reaction time. Participants then sequentially completed a 10 minute warm-up (Table 2).

Table 2. Dynamic warmup for plyometrics (Haff & Triplett, 2016).

Exercise	Volume
Stationary Cycling	5 minutes at self-selected intensity
Marching	10 repetitions
Skipping	10 repetitions
Lunging	10 repetitions

After the warm-up, participants rested for 3 minutes and then practiced performing the DJ movement under conditions of full vision and stroboscopic vision. For DJs performed under condition of stroboscopic vision, participants wore stroboscopic goggles (Senaptec LLC, Beaverton, OR, USA). The goggles were set to a strobe frequency of 3 Hz (transparent: 100 ms, opaque: 233 ms). Strobe frequency was selected by referencing previous investigations (Kroll et al., 2020). DJs were performed with participants standing on a plyometric box raised to be 0.51 m above the laboratory floor. A box height of 0.51 m was selected to provide maximal neuromuscular reactivity (Louder et al., 2021). Participants were asked to initiate the DJ after receiving a standard verbal cue to "jump as high and as quickly as possible upon landing from the drop". Participants were also instructed to keep their vision focused on a marker placed on the laboratory floor at a distance of 0.30 m in front of the landing surface. Participants were required to land and take-off from a force platform placed in front of the plyometric box. Participant arm motion was not restricted, which facilitated a jumping technique that better represents the performance of jumping and landing in real-world settings. During the familiarization session, participants performed approximately 6 practice trials of DJ under condition of full vision, stroboscopic trials were limited to the second visit to reduce learning effect. All practice trials were monitored by a member of the research team, with augmented feedback provided if necessary. We defined a proper DJ as landing with both feet at the same time, with the goal of minimizing the amortization phase, followed by an attempt at a maximal vertical jump, all executed with both feet successfully making contact with the force platform.

During the second visit, participants completed an experimental trial of the 7 pre-programmed VM assessments on the same tablet computer used in familiarization. Participants then completed the same 10 minute warm-up performed during the familiarization session. Participants rested for 10 minutes and then completed a single static trial to obtain static GRF data, then proceeded to execute 6 successful DJs under each condition, both the condition of full vision (control) and stroboscopic vision (experimental). Recovery time of 10 seconds between DJ's was allowed to account for fatigue. The order of conditions was counterbalanced, with all trials performed in a given condition prior to advancing to the subsequent condition. DJ trials across both conditions were performed using procedures consistent with the familiarization session with the exception that participants were required to stand static on the force platform for a period of 5 seconds after completing each jump.

Data Analysis

Data Acquisition

Visuomotor Skills. Visuomotor performance data (Table 3) was stored on the tablet immediately following the completion of each assessment. Data was exported to a spreadsheet for use in statistical analysis.

Table 3. Tablet-based visuomotor skill assessments.

Assessment	Description	Outcome Measure	Interpretation
Visual Clarity	Participants stand at a distance from the tablet and report the orientation of gaps in a Landolt ring. Landolt ring size is changed according to an adaptive staircase algorithm.	LogMAR	Lower logMAR scores represent better visual clarity.
Contrast Sensitivity	Participants stand at a distance from the tablet and report the static ring that contains light-dark contrast. Contrast is changed according to an adaptive staircase algorithm.	LogContrast	Greater logContrast scores represent better contrast sensitivity.
Depth Perception	Participants stand at a distance from the tablet and report the static ring that appears to be closest. Depth is changed according to an adaptive staircase algorithm.	Arcsec	Lower arcsec scores represent better depth perception.
Near-far Quickness	Participants stand at a distance from the tablet while holding a smartphone and report which device contains a target.	Number of correct responses in 30 s	Greater number of correct responses represent better near-far quickness.
Perception Span	Participants stand near the tablet and recreate the location of circular targets contained within a web of circles. The number of targets and web size increases when responses are correct.	Number of correct responses	Greater number of correct responses represent a better perception span.
Multiple Object Tracking	Participants stand near the tablet and track multiple spinning pairs of circles, with one circle identified as the target. After the spin is complete, participants recreate the location of targets. The number of circle pairs and spin rate are changed according to an adaptive staircase algorithm.	Composite score of threshold spin rate and tracking capacity	Greater scores represent better multiple object tracking.
Reaction Time	Participants stand near the tablet and place each index finger on a colored circle. Participants react as quickly as possible to a change in circle color by lifting the corresponding finger away from the tablet screen.	Average reaction time (ms)	Lower average times represent better reaction time.

Depth Jumps. Vertical GRF was acquired from a tri-axial force platform (1000 Hz, Model FP4080, Bertec Corporation, Columbus, OH, USA) that was recessed to be flush with the laboratory floor. Digital signals of GRF time-series data were captured with the Vicon Nexus (Version 2.12, Vicon Motion Systems Ltd., Oxford, UK) software platform.

Data Preparation

Time-series GRF signals were exported from Vicon Nexus and processed in Matlab (Version R2021a, The Mathworks Inc., Natick, MA, USA). GRF signals were passed through a 4th order, recursive Butterworth filter (300Hz cut-off frequency).

Reactive Strength Index (RSI)

Filtered GRF signals were first pared to start at the time of landing impact following the drop phase and end approximately 3 seconds following the completion of the DJ with participants holding a static pose. The timing of landing impact was defined using methods described previously (Louder et al., 2019). Using the pared signal, DJ jump height (JH) was then estimated by modifying the single force-platform approach from McMahon et al. (2021). GRF data were first converted to acceleration and then integrated using the trapezoidal rule to provide an estimate of change in vertical velocity (Δv; Equation 1). DJ take-off velocity ($v_{t\text{-}off}$) is then estimated by taking the difference between the Δv at DJ take-off and a residual estimate of landing impact velocity (v_{Impact}; Figure 1). JH was then estimated by inputting $v_{t\text{-}off}$ into an equation of constant acceleration (Equation 3). Ground contact time (GCT) was defined as the time interval between landing impact and DJ take-off. RSI scores were then estimated by taking the ratio of JH to GCT (Equation 4).

$$(1)\ \Delta v = \int acceleration = \int \frac{GRF - BW}{mass}$$

$$(2)\ v_{t-off} = \Delta v - \left| v_{Impact} \right|$$

$$(3)\ JH = \left(\frac{v_{T-off}^{2}}{19.62}\right)$$

$$(4)\ RSI = \frac{JH}{GCT}$$

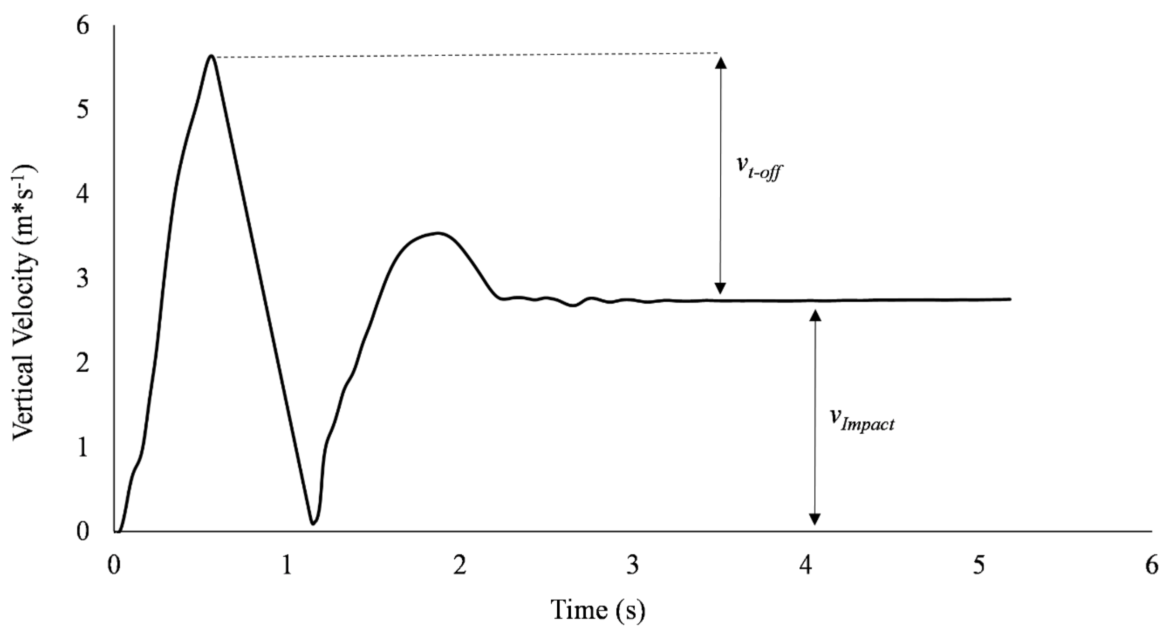

Figure 1. Estimation of $v_{t\text{-}off}$ from integrated DJ acceleration data.

Statistical Analysis

An a priori power analysis in G*Power (version 3.1) was performed using published GRF data acquired from female NCAA Division I volleyball athletes who performed DJs under condition of full vision and stroboscopic vision (Kroll et al., 2020). The power analysis indicated that a sample of 6 participants would give sufficient power for measures of peak landing GRF and RFD. With linear regression being one of the primary measures, a sample size of 10-30 subjects is recommended per predictor variable to provide for regression analysis. Statistical analyses were performed in RStudio Desktop (Version 1.1.456) with all hypothesis tests conducted using an alpha level of 0.05. Test-retest reliability of VM measures and the inter-trial reliability of DJ performance measures were assessed using intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals (95% CI) based on a single-measures, absolute agreement, two-way, mixed-effects model. Interpretation of ICC estimates was based on recommendations from Koo and Li (2016), with ICC values of 0.5, 0.5-0.75, 0.75-0.9, and values greater than 0.90 as defined as poor, moderate, good, and excellent reliability, respectively. Two-way analyses of variance (ANOVAs) were performed to evaluate for main effects and interaction between visual condition [full vision × stroboscopic vision] and trial number [1 × 2 × 3 × 4 × 5 × 6] on RSI scores, JH, and GCT. Upon observation of a significant interaction, post-hoc analysis was performed using a one-way repeated measures ANOVA, followed with paired *t*-tests to evaluate for main effects and statistical significance of visual condition on trial number. Upon the observation of significant main effects of visual condition, post-hoc analysis was performed using paired *t*-tests to evaluate for statistical significance of visual condition on RSI scores and JH. Cohen's *d* effect sizes were estimated using pooled standard deviations.

Prior to the linear regression analysis, the RSI scores, GCT, and JH of each participant were averaged across trials for both full vision and stroboscopic vision conditions. Change scores were then computed by subtracting the average values for full vision by the average values for stroboscopic vision. Simple linear regression was performed to evaluate for mediating effects of VM skill (predictor) on RSI, JH, and GCT change scores (response).

Results

Reliability

Moderate to excellent test-retest reliability was observed for VM tests of visual clarity, depth perception, multiple object tracking, and reaction time (Table 4), with poor to moderate reliability observed for contrast sensitivity, near-far quickness, and perception span (Table 4). Inter-trial reliability was good to excellent for RSI scores, JH, and GCT across both visual conditions (Table 5).

Table 4. Test-retest reliability of visuomotor measures

Measure	Familiarization	Test	ICC
Visual Clarity	-0.0867 (0.264)	-0.0664 (0.270)	0.87 (0.71-0.94)
Contrast Sensitivity	1.491 (0.307)	1.545 (0.316)	0.43 (0.03-0.71)
Depth Perception	162.8 (88.2)	144.0 (88.4)	0.82 (0.62-0.92)
Near-far Quickness	20.3 (5.6)	22.9 (6.7)	0.36 (-0.03-0.66)
Perception Span	42.5 (12.0)	44.9 (14.0)	0.36 (-0.06-0.68)
Multiple Object Tracking	1493.8 (628.6)	1467.4 (575.8)	0.79 (0.56-0.91)
Reaction Time	317.5 (31.3)	325.1 (38.6)	0.84 (0.65-0.93)

Familiarization and test results are presented as mean (SD). Intraclass correlation coefficients ICCs) are presented as ICC estimate (95% CI).

Table 5. Inter-trial reliability of depth jump performance measures

Measure	Full Vision	Stroboscopic Vision
RSI	0.92 (0.86-0.96)	0.91 (0.84-0.96)
JH	0.93 (0.88-0.97)	0.91 (0.84-0.96)
GCT	0.90 (0.83-0.95)	0.93 (0.88-0.97)

Intraclass correlation coefficients (ICCs) are presented as ICC estimate (95% CI). RSI = reactive strength index; JH = jump height (m); GCT = ground contact time (s).

ANOVA

There was a significant visual condition × trial number interaction on JH ($F = 3.3$, $p = 0.008$). Post-hoc analysis revealed that JH under condition of full vision was significantly greater than JH under condition of stroboscopic vision for trial numbers 1, 2, 4, and 5 ($p < 0.001$-0.021; Figure 2), with no differences observed for trial numbers 3 and 6 ($p = 0.064$-0.096; Figure 2). There were no significant visual condition × trial number interactions on RSI scores ($F = 2.1$, $p = 0.070$) or GCT ($F = 0.4$, $p = 0.850$).

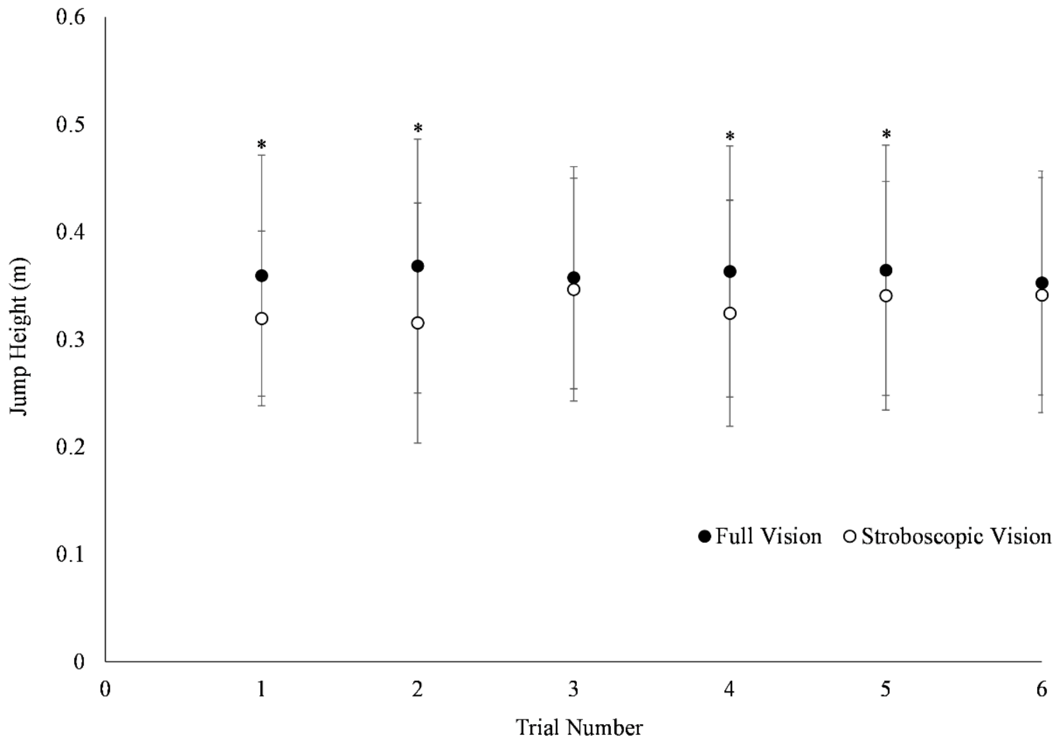

Figure 2. Visual condition × trial number interaction on jump height (m). Error bars represent ± standard deviation. *$p < 0.05$.

Main effects of visual condition were observed on RSI scores ($F = 10.5$, $p = 0.004$) and JH ($F = 41.4$, $p < 0.001$). Post-hoc analysis revealed that RSI scores and JH were greater under condition of full vision in comparison with stroboscopic vision ($p < 0.001$; Table 6), with small effect sizes observed for both dependent measures (Table 6). No main effect of visual condition was observed for GCT ($F = 0.0$, $p = 0.872$) and there were no main effects of trial number on RSI scores ($F = 1.2$, $p =0.301$), JH ($F = 1.4$, $p = 0.231$), or GCT ($F = 1.3$, $p = 0.261$).

Table 6. Main effects of visual condition on depth jump performance measures

Measure	Full Vision	Stroboscopic Vision	Cohen's *d*
RSI	0.82 (0.38)*	0.75 (0.32)	0.21
JH	0.36 (0.11)*	0.33 (0.10)	0.28
GCT	0.48 (0.12)	0.48 (0.12)	0.01

Data are presented as mean (standard deviation). RSI = reactive strength index (m/s); JH = jump height (m); GCT = ground contact time (s). *Significantly different from stroboscopic vision ($p < 0.05$).

Linear Regression

No significant linear relationships were observed between visuomotor skill and DJ performance change scores (Tables 6-8).

Table 7. Linear regression results on RSI change scores (response)

Predictor	Model	F (p-value)	R^2
Visual Clarity (VC)	0.03(VC) – 0.06	0.25 (0.624)	0.00
Contrast Sensitivity (CS)	0.05(CS) – 0.13	0.92 (0.350)	0.00
Depth Perception (DP)	$7.5e^{-5}$(DP) – $6.8e^{-2}$	0.14 (0.714)	0.00
Near-far Quickness (NFQ)	$-5.1e^{-4}$(NFQ) – 0.05	0.04 (0.848)	0.00
Perception Span (PS)	$-1.4e^{-3}$(PS) + $5.8e^{-3}$	1.4 (0.245)	0.02
Multiple Object Tracking (MOT)	$10.0e^{-6}$(MOT) – $7.1e^{-2}$	0.09 (0.764)	0.00
Reaction Time (RT)	0.69(RT) – 0.30	0.14 (0.711)	0.02

Table 8. Linear regression results on JH change scores (response)

Visuomotor Test	Model	F (p-value)	R^2
Visual Clarity (VC)	$5.5e^{-3}$(VC) – 0.03	0.09 (0.765)	0.00
Contrast Sensitivity (CS)	$-7.9e^{-3}$(CS) – 0.02	0.28 (0.601)	0.00
Depth Perception (DP)	$4.8e^{-5}$(DP) – $3.7e^{-2}$	0.77 (0.393)	0.00
Near-far Quickness (NFQ)	$-4.9e^{-4}$(NFQ) – 0.02	0.47 (0.500)	0.00
Perception Span (PS)	$-1.1e^{-4}$(PS) – 0.02	0.11 (0.743)	0.00
Multiple Object Tracking (MOT)	$-5.3e^{-6}$(MOT) – $2.2e^{-2}$	0.34 (0.57)	0.00
Reaction Time (RT)	0.11(RT) – 0.07	0.93 (0.348)	0.00

Table 9. Linear regression results on GCT change scores (response)

Visuomotor Test	Model	F (p-value)	R^2
Visual Clarity (VC)	$-3.3e^{-2}$(VC) – $3.1e^{-3}$	0.80 (0.381)	0.00
Contrast Sensitivity (CS)	0.02(CS) – 0.03	0.39 (0.541)	0.00
Depth Perception (DP)	$-1.3e^{-4}$(DP) +0.02	1.35 (0.260)	0.02
Near-far Quickness (NFQ)	$1.7e^{-3}$(NFQ) – 0.04	1.27 (0.274)	0.01
Perception Span (PS)	$-1.8e^{-4}$(PS) + $6.4e^{-3}$	0.06 (0.805)	0.00
Multiple Object Tracking (MOT)	$-3.5e^{-5}$(MOT) + $4.8e^{-2}$	4.07 (0.06)	0.13
Reaction Time (RT)	-0.32(RT) + 0.10	1.55 (0.229)	0.03

Discussion

The purpose of this study was to evaluate the association between visuomotor skills and the effects of stroboscopic vision on DJ performance. Differences observed between visual conditions demonstrated higher RSI scores for DJs performed under full vision when compared to stroboscopic vision. Specifically, a reduction of 8.5% was seen in RSI scores for DJs performed under condition of stroboscopic vision. These findings are consistent with the findings of Kroll et al. (2020), who observed a 6.3% reduction in RSI scores when female collegiate volleyball players performed 0.38m DJs under condition of 4 Hz stroboscopic vision versus full vision, respectively (Kroll et al., 2020). In the present investigation, the change in RSI scores was predominantly due to a significant 8.3% reduction in JH for DJs performed under condition of stroboscopic vision with no differences observed for GCT. The absence of an effect on GCT is supported by the findings of Kroll et al. (2020), who observed no change in GCTs when female collegiate volleyball players performed 0.38m DJs under condition of 4 Hz stroboscopic vision versus full vision.

There were no linear relationships observed between VM skill and DJ performance change scores. It is important to note that poor to moderate test-retest reliability was observed for VM tests of contrast sensitivity, near-far quickness, and perception span, which may have contributed to the lack of a mediating relationship with DJ change scores. It may be the case that participants' inconsistent performance on these tests was affected by cognitive state or the proprietary design of the assessments. The test-retest reliability for VM tests of visual clarity, depth perception, multiple object tracking, and reaction time was moderate to excellent, yet participant performance on these tests was also not observed to mediate DJ change scores. We elected to include VM data from the second testing session in our statistical analysis in lieu of averaged performance as the testing session occurred immediately prior to the collection of DJ performance data. The reliability statistics observed for VM tests suggest that more than two assessments on the tablet used in the present investigation are necessary to derive reliable estimates of VM skill, which may be addressed through additional study.

The lack of linear relationships observed in the present investigation may simply be due to the fact that VM skill does not mediate the effect of stroboscopic vision on DJ performance. When compared to open skills in sport such as jumping and landing in competition, the DJ is a more discrete and closed skill that has been suggested to rely primarily on feedforward motor control (Santello, 2005). The view that feedforward motor control is the main DJ control mechanism is supported by the findings of the present investigation. The lack of a mediating relationship between VM skill and DJ change scores in addition to small effect sizes observed for JH and RSI under condition of stroboscopic vision support the notion that DJs are effectively planned if the dropping height is viewed prior to movement initiation and that there is minimal contribution from online visual feedback.

A literature review by Laby and Appelbaum (2021) summarizes current literature relating to the relationship between VM skill and sport performance as well as the potential for VM training to improve sport-specific performance data. A majority of the investigations reviewed were conducted on collegiate and professional baseball players, with Laby and Appelbaum (2021) finding that a majority of the literature has revealed significant correlations between VM skill and batting metrics (6/8, 75%) in addition to significant positive effects of VM training on batting performance (7/7, 100%). Though the present investigation did not provide evidence to support a relationship between VM skill and DJ change scores, there is reason to believe that VM training may lead to an increase of movement performance over time. With evidence supporting that DJs are primarily a pre-planned movement, further investigation is required to assess whether there is a relationship between VM skill and jump landing and takeoff mechanics performed in an open-sport setting.

Important to note is that multiple object tracking performance approached significance as a mediator of GCT change scores despite the absence of a main effect of visual condition on GCT. Kroll et al. (2020) observed significantly longer GCTs (+6.5%, $d = 0.43$) when DJs were performed under 1.75 Hz stroboscopic vision, with no effect observed for DJs performed under 4 Hz stroboscopic vision. A limitation of the present investigation may be that a strobe intensity of 3 Hz did not disrupt online vision enough to elicit a measurable effect on GCTs or significant linear relationships between VM skill and DJ change scores.

The RSI and its component measures were evaluated for linear relationships with VM skill in the present investigation. It is important to mention that these measures are considered broad metrics of DJ performance, thus it may be the case that VM skills do not associate DJ performance broadly. Alternatively, VM skills may associate to a greater extent with variables that are more closely related to the timing of landing impact (e.g. impact velocity, peak GRF, rate of GRF development, vertical stiffness, and peak GRF reduction). Further investigation is required to determine whether there is a mediating relationship between VM skill and DJ performance data that are more specific to the mechanics of landing impact.

In addition to the lack of multiple stroboscopic intensities and the inclusion of broad DJ performance metrics, the absence of joint kinematics and kinetics as dependent measures is a limitation of the present investigation. From visual observation, there appeared to be a clear difference in landing and takeoff kinematics between visual conditions. In order to better understand the extent that VM skills may mediate DJ performance under condition of stroboscopic vision, it is suggested to consider including joint kinematics and kinetics in future research.

Conclusion

DJ performance was influenced by 3 Hz stroboscopic vision, however, VM skill showed no significant linear association with RSI, JH, and GCT change scores. The observation that stroboscopic vision influences RSI scores and JH could be a result of altered joint-level landing and takeoff mechanics or GRF measures that more closely related to landing impact. The findings of the present investigation support the current postulation that DJ performance is largely planned via feedforward control upon a visual scan of the environment (e.g. drop height) and may not depend on online visual feedback, which is contrary to the hypothesis of the present investigation. Further investigation is warranted to evaluate whether the lack of a mediating relationship between VM skill and DJ performance change scores is replicated under differing levels of stroboscopic intensity and an expansion of mechanical variables that relate more closely to the drop landing impact phase of the DJ.

References

Bastian, A. J. (2006). Learning to predict the future: The cerebellum adapts feedforward movement control. *Current Opinion in Neurobiology*, *16*(6), 645–649. https://doi.org/10.1016/j.conb.2006.08.016

Chu, D. (1998). *Jumping into plyometrics*. Human Kinetics.

Haff, G., & Triplett, N. (2016). *Essentials of strength training and conditioning, 4ed*. Human Kinetics. Retrieved September 9, 2021, from https://www.nsca.com/store/product-detail/INV/9781718210868/9781718210868

Herman, D. C., & Barth, J. T. (2016). Drop-jump landing varies with baseline neurocognition: implications for anterior cruciate ligament injury risk and prevention. *The American Journal of Sports Medicine*, 44(9), 2347–2353. https://doi.org/10.1177/0363546516657338

Kim, K.-M., Kim, J.-S., & Grooms, D. R. (2017). Stroboscopic vision to induce sensory reweighting during postural control. *Journal of Sport Rehabilitatio*n, *26*(5). https://doi.org/10.1123/jsr.2017-0035

Komi, P. (2008). *Strength and power in sport*. Wiley-Blackwell.

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Kroll, M., Preuss, J., Ness, B. M., Dolny, M., & Louder, T. (2020). Effect of stroboscopic vision on depth jump performance in female NCAA Division I volleyball athletes. *Sports Biomechanics*, 1–11. https://doi.org/10.1080/14763141.2020.1773917

Laby, D. M., & Appelbaum, L. G. (2021). Vision and on-field performance: a critical review of visual assessment and training studies with athletes. *Optometry and Vision Science: Official Publication of the American Academy of Optometry*, *98*(7), 723–731. https://doi.org/10.1097/OPX.0000000000001729

Leukel, C., Taube, W., Lorch, M., & Gollhofer, A. (2012). Changes in predictive motor control in drop-jumps based on uncertainties in task execution. *Human Movement Science,* 31(1), 152–160. https://doi.org/10.1016/j.humov.2011.04.006

Louder, T., Thompson, B. J., Banks, N., & Bressel, E. (2019). A mixed-methods approach to evaluating the internal validity of the reactive strength index. *Sports*, *7*(7), 157. https://doi.org/10.3390/sports7070157

Louder, T., Thompson, B. J., & Bressel, E. (2021). association and agreement between reactive strength index and reactive strength index-modified scores. *Sports*, 9(7), 97.

Magalhães, F. H., & Goroso, D. G. (2009). Preparatory EMG activity reveals a rapid adaptation pattern in humans performing landing movements in blindfolded condition. Perceptual and Motor Skills, 109(2), 500–516. https://doi.org/10.2466/PMS.109.2.500-516

McMahon, J. J., Lake, J. P., Stratford, C., & Comfort, P. (2021). A proposed method for evaluating drop jump performance with one force platform. *Biomechanics*, *1*(2), 178–189. https://doi.org/10.3390/biomechanics1020015

Montalvo, S., Gonzalez, M. P., Dietze-Hermosa, M. S., Eggleston, J. D., & Dorgo, S. (2021). Common vertical jump and reactive strength index measuring devices: a validity and reliability analysis. J*ournal of Strength and Conditioning Research*, 35(5), 1234–1243. https://doi.org/10.1519/JSC.0000000000003988

Santello, M. (2005). Review of motor control mechanisms underlying impact absorption from falls. *Gait & Posture*, 21(1), 85–94. https://doi.org/10.1016/j.gaitpost.2004.01.005