DOI: https://doi.org/10.5114/biolsport.2020.97070

Increased visual distraction can impair landing biomechanics

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ABSTRACT: Failed jump landings represent a key mechanism of musculoskeletal trauma. It has been speculated that cognitive dual-task loading during the flight phase may moderate the injury risk. This study aimed to explore whether increased visual distraction can compromise landing biomechanics. Twenty-one healthy, physically active participants (15 females, 25.8 ± 0.4 years) completed a series of 30 counter-movement jumps (CMJ) onto a capacitive pressure platform. In addition to safely landing on one leg, they were required to memorize either one, two or three jersey numbers shown during the flight phase (randomly selected and equally balanced over all jumps). Outcomes included the number of recall errors as well as landing errors and three variables of landing kinetics (time to stabilization/TTS, peak ground reaction force/pGRF, length of the centre of pressure trace/COPT). Differences between the conditions were calculated using the Friedman test and the post hoc Bonferroni-Holm corrected Wilcoxon test. Regardless of the condition, landing errors remained unchanged ($p = .46$). In contrast, increased visual distraction resulted in a higher number of recall errors ($chi^2 = 13.3$, $p = .001$). Higher cognitive loading, furthermore, appeared to negatively impact mediolateral COPT ($p < .05$). Time to stabilization ($p = .84$) and pGRF ($p = .78$) were unaffected. A simple visual distraction in a controlled experimental setting is sufficient to adversely affect landing stability and task-related short-term memory during CMJ. The ability to precisely perceive the environment during movement under time constraints may, hence, represent a new injury risk factor and should be investigated in a prospective trial.

CITATION: Wilke J, Giesche F, Niederer D et al. Increased visual distraction can impair landing biomechanics. Biol Sport. 2021;38(1):123–127.

Received: 2020-01-14; Reviewed: 2020-05-06; Re-submitted: 2020-07-06; Accepted: 2020-07-06; Published: 2020-08-08.

Key words:
Neurocognition
Injury
Jumping
Athletes
COINS

INTRODUCTION

The human brain allows for the acquisition and recall of innumerable motor skills. Their execution is characterized by high precision and repeatability as long as full attention is paid to the respective task. However, daily life often requires a divided focus: Cognitive distraction (e.g. making a phone call, reading street signs, or listening to music) during habitual movement places demands on the brain's information processing capacity, potentially impairing its ability to govern the motor action. Initial evidence supports this hypothesis: Mental distraction decreases postural stability [1], alters gait kinematics [2], and modifies obstacle clearance [3].

Dual-task interference leading to impaired motor performance may have severe consequences in sports. Typically, athletes need to monitor a plethora of highly dynamic external factors (e.g., teammates' and opponents' commands and actions, ball movement), while simultaneously executing and adjusting their own motor plans under high time constraints. It, therefore, could be assumed that the combination of quick, powerful movements such as changes of direction, cutting movements or jump landings and complex cognitive loading increases the odds of sustaining an injury [4].

In a pioneering study, Shinya, Wada, Yamada, Ichihashi & Oda [5] instructed their participants to perform a series of bilateral jumps, landing as softly as possible on the right leg. During the flight phase of some trials, an auditory signal requiring a button press was presented. Compared to the control condition without the stimulus, the dual task led to higher ground reaction forces upon landing. Using a slightly different approach, Dai et al. [6] examined the influence of counting aloud vs. no counting on landing mechanics. Besides increased ground reaction forces, they observed decreased knee flexion angles in the dual task condition. Although the findings of both trials are intriguing, distraction based on visual input seems to be of higher relevance in sport because its processing, arguably, is paramount for injury prevention.

A series of studies investigated the impact of visual distraction in situations mimicking sports activity. Related experiments were mostly based on the concurrent execution of two motor tasks with one of them representing the distraction. Monfort et al. [7] asked their participants to dribble a soccer ball while performing a cutting movement. In other trials, a basketball had to be passed during a similar manoeuvre [8] or rebounded during a jump [9]. In all these cases, not only the main task (cutting or landing) but also the distraction task (dribbling, passing or catching the ball) demanded motor cortex activity which may have led to the observed biomechanical impairments. However, from a theoretical point of view, an interference effect could even be provoked by a non-motor distraction exclusively requiring sensory (i.e. visual) brain resources. As this hypothesis has not been tested, hitherto, our trial addressed the question as to whether non-motor visual-cognitive loading during the flight phase of a jump could compromise landing mechanics. We hypothesized that increased levels of distraction would decrease postural stability as a result of divided attention.

MATERIALS AND METHODS

Ethical standards and study type

This study, performed in accordance with the standards of the Helsinki Declaration, is part of the ******* (****) network project (Clinical trials: *******). It adopted a randomized crossover design with three conditions performed on the same day. Approval was obtained from the local ethics committee and all participants provided written informed consent.

Sample

Twenty-one healthy, individuals (15 females, 25.8 ± 0.4 years, 171 ± 7 cm, 68 ± 12 kg) volunteered to participate. They were students from the university's sports science Bachelor's and Master's programmes. Habitual sporting activity volume was 8 ± 3 hours per week. The majority of the participants engaged in team and ball sports such as football (soccer), basketball and handball. Exclusion criteria were history of lower leg injury, severe orthopaedic, cardiopulmonary, neuronal, endocrine, and psychiatric diseases, pregnancy or nursing period, muscle soreness, (uncorrected) visual impairments and analgesic drug intake within the past 48 hours. Recruitment was performed by means of personal addressing and posting of flyers.

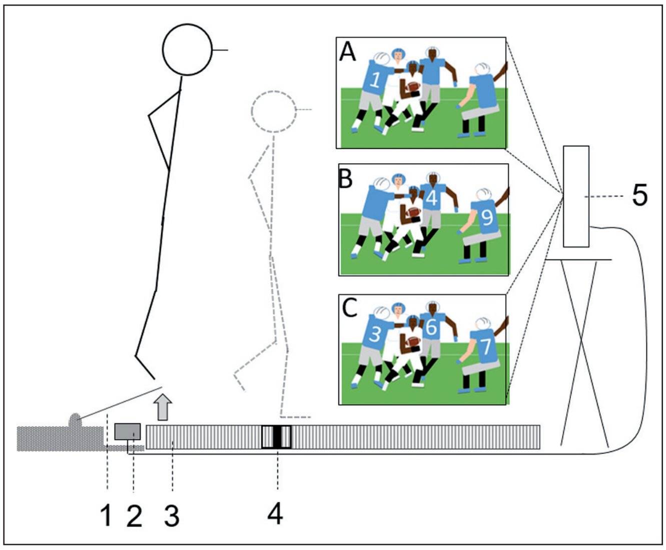

Fig. 1. Schematic illustration of the experimental setup. Standing on a plastic panel (1), thus holding a button switch (2) pressed, the participants jumped onto a target (4) on a pressure plate (3). At take-off, the button switch was released, initiating a slide change on a screen (5) in front of the participants. Either one, two or three jersey number were shown on the new slide which disappeared prior to landing.

Jump-landing task

The experiment is depicted in *Fig.1*. All participants performed 30 bilateral counter-movement jumps (CMJ) onto a capacitive pressure platform (50 Hz, Zebris FDM, Zebris Medical GmbH, Isny, Germany). The one-legged landing position had to be maintained as stable as possible for 20 seconds. To standardize jump distance (about 100 cm), a tape line on the pressure plate indicated the target location for landing. All jumps within 10% (10 cm) deviation from the target distance were considered valid.

Each of the jumps was performed at varying degrees of visual demand. It consisted of a photo depicting a typical game situation in American Football and was briefly (150 ms) shown during the flight phase. While the photo remained the same, depending on the condition, either one (N1), two (N2), or three (N3) shirt numbers (single digits) of the depicted players were presented. No attentional focus (such as 'look to the right') was determined regarding the photo shown. Instead, generally fixating the monitor during the flight, the participants were asked to memorize the shirt number(s) seen during jumping and to land as securely as possible. Ten seconds after ground contact, the numbers shown had to be repeated verbally. To prevent exhaustion, the 30 jumps were split into blocks of six (two for each condition) with two-minute rest intervals in between. The order of the three equally distributed conditions was chosen randomly for each jump.

The display of the photo providing the visual distraction was triggered using a USB button switch positioned under a plastic panel just in front of the pressure plate. The switch was connected to a 17-inch laptop screen showing the photo via presentation software (PowerPoint, Microsoft, USA (*Fig. 1*)). In all jumps, the participants started standing on the panel, thus keeping the button pressed. Upon jumping, the button was released, initiating a slide change from a white slide to the image of the respective distraction condition. The delay between the button release and the appearance of the new slide (combined latency of button switch and presentation software) was about 120 ms. Distraction thus reliably occurred during the initial flight phase.

Outcome assessment

Flight time, landing errors (e.g. ground contact of free leg or leaving the pressure plate) and recall errors (false memorization of jersey number(s)) were documented. In addition, three correlates of postural control were analysed: peak ground reaction force (pGRF), time to stabilization (TTS), and centre of pressure trace lengths (COPT). The pGRF represents the highest vertical force impact [N] measured after landing and was obtained from raw data. The TTS [s] is a reliable measure of the time needed to achieve a stable stance [10]. It was calculated using the dynamic cumulative average weight based on the continuous platform recordings until 15 seconds after landing. A stable stance was defined as the point where the sequential average no longer exceeded the threshold of .25 standard deviations of the overall mean ground reaction force [10, 11]. Finally, the total, mediolateral and anteroposterior COPT were determined during TTS time. Measurements of COPT have been shown to exhibit high reliability [12].

Statistical analysis

Due to non-normal data distribution, differences between the three testing conditions (N1, N2, N3) were calculated using the Friedman test. In the case of significance, the pairwise post hoc Wilcoxon test with Bonferroni-Holm correction were performed. Associations within results (e.g. recall errors and biomechanical variables) as well as between results and potential confounders (e.g. baseline jump height or anthropometric data) were evaluated using Spearman correlations. All computations were made with SPSS Statistics, version 22 (IBM, USA). The significance level was set to $\alpha = .05$.

RESULTS

All participants completed the experiment. The achieved flight times (median: 337 ± 62 ms) were not different between (p = .66) and stable within the three conditions (relative coefficients of variation between 4.0 and 4.1%). Baseline jump height, perceived exertion and task difficulty as well as anthropometric data had no influence on the below outcomes (p>.05).

Landing and recall errors

Irrespective of the condition, the number of landing errors remained unchanged (p = .46). In contrast, more recall errors were observed at increased cognitive loading (chi^2 = 13.3, p = .001, *Table 1*): According to post hoc testing, N2 (z = 2.64, p = .016) and N3 (z = 3.34, p = .003) led to significantly more false memorizations when compared to N1. No significant difference was found between N2 and N3 (z = 1.78, p = .08).

Landing biomechanics

While pGRF (p = .78) and TTS (p = .84) remained unaffected by the level of visual distraction, COPT varied as a function of visual distraction. Although the comparison of total COPT failed to reach statistical significance (chi^2: 5.4, p = .07), analysis of the two trace directions revealed that landing stability was slightly impaired in the mediolateral dimension (chi^2 = 8.5, p = 0.01): Trace length was not different between N1 and N2 (p = .24), but the participants exhibited higher postural sway during N3, when compared to N1 (z = 2.5, p = .03). Recall errors were not associated with the landing biomechanics (p >.05).

TABLE 1. Landing and standing errors as well as biomechanical landing stability in the three conditions.

	N1	N2	N3	Comparisons
Landing Errors [n]	1 (0–3)	1 (0–3)	1 (0–4)	Chi^2 = 1.54, p = .46
Recall Errors [n]	1 (0–3)	2 (0–5)	3 (0–8)	Chi^2 = 13.3, p = .001 N1–N2: p = .008, p_{corr} = .016 N1–N3: p = .0001, p_{corr} = .0003 N2–N3: p = .08, p_{corr} = .08
pGRF [N]	2,130 (1,090–3,480)	2,150 (1,110–3,320)	2,160 (1,090–3,510)	Chi^2 = .51, p = .78
TTS [s]	1.87 (1.56–2.18)	1.81 (1.60–2.19)	1.82 (1.57–2.20)	Chi^2 = .34, p = .84
COPT, total [mm]	323 (251–375)	340 (254–374)	332 (233–471)	Chi^2 = 5.4, p = .07
COPT, medio-lateral [mm]	261 (218–322)	273 (214–345)	270 (224–314)	Chi^2 = 8.46.3, p = .01 N1–N2: p = .19, p_{corr} = .24 N1–N3: p = .01, p_{corr} = .03 N2–N3: p = .12, p_{corr} = .24
COPT, antero-posterior [mm]	643 (455–814)	646 (461–815)	643 (482–804)	Chi^2 = 0.29, p = .87

Values represent medians including ranges (minimum to maximum). COPT: center of pressure trace, TTS: Time to Stabilization, pGRF: peak Ground Reaction Force, N: number of jerseys, p_{corr}: corrected pa value.

DISCUSSION

The potential significance of neurocognitive function during athletic movement has become a major focus of recent research. Previous trials have shown that mental-verbal (counting, [6]), auditory (reacting to a noise, [5]) and visual-motor loading during the flight phase of a jump lead to impairments in landing safety [9]. Our study, which is the first to elucidate the influence of varying, purely cognitive sports-related visual distraction on landing biomechanics, corroborates and extends their findings. Even in a controlled experimental setting and without the necessity of a direct motor response, an increasingly complex stimulus can negatively affect dynamic postural control.

Although several theories exist to explain dual task interferences [13], it may be speculated that higher cognitive loading – as induced by the task to memorize more shirt numbers – occupies additional brain resources which would originally be needed in order to execute and adjust the a priori selected motor plan. In any case, the interaction between visuo-cognitive loading and landing stability may be of importance with regard to injury prevention and should be further examined in field settings.

As indicated, no previous study has focused on the potential impact of variable, non-motor visual distraction. Notwithstanding, a few trials have investigated landing stability with normal or reduced vision. Grooms et al. [14] used stroboscopic glasses to impair sight in a sample of ACL-reconstructed and healthy individuals. Besides modifying ground reaction forces, vertical drop landings with glasses produced altered knee excursions in the sagittal and frontal plane. Also Santello et al. [15] examined drop jump landings, but instructed the participants to keep their eyes open or closed. When vision was withheld, the authors measured 10% higher ground reaction forces and different knee joint rotation patterns when compared to the unimpaired control condition. Finally, using a similar design, Chu et al. [16] demonstrated decreased knee flexion and asymmetric maximal dorsiflexion timing between legs with closed eyes. While our finding of decreased landing stability is in line with the findings of all these trials, it has to be reiterated that we did not obstruct vision in any way. This fact impressively shows that the impact of optical perception on dynamic postural control following a jump reaches beyond having normal or reduced sight.

Despite the intriguing findings of our study, the changes in landing biomechanics (three to five percent) were small and only affected one parameter. The direct clinical implications of our research are thus unclear. Notwithstanding, for several reasons, higher impairments may occur in a real-world sport setting. Firstly, our recall task during jumping included a static, non-moving object. Tracking and major eye movements were thus not required. Ocular motion however, crucial during the observation of a dynamic three-dimensional environment, has been shown to be related to impaired postural stability [17, 18]. Experiments with moving objects will, hence, probably induce greater impairments in landing stability. Another aspect relates to the type of visual distraction applied. The participants of the present study had to memorize and recall a maximum of three single-digit numbers. This can be expected to be easier than monitoring a multitude of unforeseen, more complex factors (e.g. speed, distance, position of balls, opponents or team mates). Connected to this, cognitive loading in real sports is not restricted to simple information storage but also includes the use of working memory (interpretation and manipulation of perceived stimuli) and other neurocognitive domains such as inhibitory control and cognitive flexibility. Lastly, the jump landings were anticipated in nature and the participants, most likely, relied on the pre-planned execution of an almost automated movement. Again, in sports, conditions may be different: unforeseen stimuli require adaptations of the original motor plan and it cannot be expected that a landing can be performed exactly as originally intended. Under these circumstances, visual distraction may impede postural control more strongly.

In addition to slightly decreasing landing stability, more complex distraction also increased the number of recall errors. It has been hypothesized in previous studies that the brain may adopt a posture first strategy [19], sacrificing successful information storage in order to maintain motor control and prevent injury. However, if this were the case, the observed errors might still be of relevance. In our experiment, the correct recall of a jersey number did not have meaningful implications regarding the risk of injury. During sports, however, the precise identification of a threat such as a quickly approaching opponent is paramount for the adequate and timely initiation of a protective manoeuvre.

Our results may impact clinical practice. While a plethora of traditional strategies attempting to estimate and reduce injury risk have focused on motor aspects such as strength, rate of force development, muscle recruitment patterns or landing technique, our findings provide new insights into the significance of cognitive function. As mentioned above, it is highly conceivable that the ability to quickly perceive and process visual stimuli represents the basis for an adequate and precise motor action. This seems particularly relevant because the characteristics of ball sports have changed dramatically. Over the past years, game speeds and action rates in Australian and European football rose by about 15 to 50% [20, 21]. As such development has been suggested to be associated with a higher risk of injury [22], therapists and conditioning coaches may consider (1) performing sports-related vision testing when screening athletes and (2) developing training methods that increase the ability to perceive and process visual stimuli applied during complex movement. Verifying the injury-predictive and injury-preventive value of such actions in healthy athletes should be the subject of further research. Moreover, it would be worthwhile to investigate the effect of visual distraction in individuals with a history of injury. The ligaments of the ankle and the knee are densely populated with mechanoreceptors [23, 24] which can be disrupted or disconnected during trauma. It is assumed that such injury-induced de-afferentiation is compensated by the visual receptor [14]. While persisting eye-dominant sensory feedback following injury may not cause problems in normal life, it may be a hazard during sports: if increasing speed and a multitude of information exceed the working capacity of the visual system, the kinaesthetic impairments can no longer be compensated. Engaging the visual system of previously injured individuals during landing by means of experimental distraction may, hence, lead to stronger impairments of dynamic posture control.

Some shortcomings need to be discussed. A pressure plate was used to examine landing biomechanics. Although we were able to detect some rather small differences between conditions, the sampling rate may have been too low to identify others. Future studies should therefore include force plates with 1,000 and more Hz to increase outcome sensitivity. Another issue relates to the number of studied parameters. To reduce alpha error accumulation, we adjusted for multiple testing within each variable. However, as we had several biomechanical outcomes (e.g. COPT dimensions and TTS) relating to the same hypothesis, a correction would have been possible here, too. Although representing a general issue in many biomechanical studies, this should be considered when interpreting the study findings.

CONCLUSIONS

Increasing the amount of visual distraction during the flight phase of a non-contact counter-movement jump reduces recall precision and, to a minor degree, biomechanical landing quality even in the absence of an additional motor task. Further study elucidating the relevance of this finding for sports performance and injury prevention is warranted.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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