Reaction Time and Joint Kinematics During Functional Movement in Recently Concussed Individuals

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Abstract

Objective: To compare movement reaction time and joint kinematics between athletes with recent concussion and matched control recreational athletes during 3 functional tasks.

Design: Cross-sectional.

Setting: Laboratory.

Participants: College-aged recreational athletes (N=30) comprising 2 groups (15 participants each): (1) recent concussion group (median time since concussion, 126d; range, 28–432d) and (2) age- and sex-matched control group with no recent concussions.

Interventions: We investigated movement reaction time and joint kinematics during 3 tasks: (1) jump landing, (2) anticipated cut, and (3) unanticipated cut.

Main Outcome Measures: Reaction time and reaction time cost (jump landing reaction time−cut reaction time/jump landing reaction time×100%), along with trunk, hip, and knee joint angles in the sagittal and frontal planes at initial ground contact.

Results: There were no reaction time between-group differences, but the control group displayed improved reaction time cost (10.7%) during anticipated cutting compared with the concussed group (0.8%; $P=.030$). The control group displayed less trunk flexion than the concussed group during the nondominant anticipated cut (5.1° difference; $P=.022$). There were no other kinematic between-group differences ($P\geq.079$).

Conclusions: We observed subtle reaction time and kinematic differences between individuals with recent concussion and those without concussion more than a month after return to activity after concussion. The clinical interpretation of these findings remains unclear, but may have future implications for postconcussion management and rehabilitation.

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Concussion results in numerous symptoms[1] and cognitive[2,3] and static balance deficits.[4] Most athletes typically demonstrate recovery in common assessment measures in these domains in 7 to 10 days.[5] Researchers using more sophisticated laboratory measures have observed dynamic gait balance discrepancies that persist beyond the resolution of deficits observed using traditional assessment tools.[6-8] However, athletes return to participation (RTP) as soon as they have been cleared on traditional measures (symptom reporting, static balance assessment, and neurocognitive assessment), raising the issue of whether some RTP decisions are potentially premature. The potential consequences of returning to play with persisting dynamic balance impairments are unknown, but may contribute to an increased risk of musculoskeletal injury after concussion.[9-14]

The mechanisms underlying an increase in the risk of musculoskeletal injury after RTP after concussion have not yet been established, but one hypothesis is that neuromuscular control

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(the many aspects that contribute to how the central nervous system controls muscle activation and postural control[15]) continues to be affected beyond RTP.[11,13,14,16] Several preliminary investigations into cortical hypoexcitability after concussion have observed lower intracortical facilitation,[17] lower maximal voluntary muscle activation,[17] and increased intracortical inhibition[18] compared with control participants. These observed differences are relatively small; however, the consequences of these mild deficits during dynamic activities of sport participation remain to be determined. When cortical hypoexcitability deficits are combined with a dynamic sport environment, it is possible that functional reaction time may be affected, increasing overall risk for musculoskeletal injury. Understanding how athletes react and move in situations that more closely resemble the dynamic nature of sport is needed to further inform the impaired neuromuscular control hypothesis after recovery from brain injury.

Recently, researchers have described lower extremity joint stiffness changes after concussion in college athletes.[19] Athletes who suffered concussion during their competitive season demonstrated increased hip stiffness and decreased knee and leg stiffness when comparing post- with preseason measures, whereas no stiffness changes were noted in athletes who did not suffer concussion. These postseason measures were taken, on average, >45 days after the concussion. Although the implications of these findings are unclear, this evidence supports the hypothesis that neuromuscular control alterations after concussion may affect functional movement during sport-specific activities.

The purpose of this investigation was to examine neuromuscular control during sport-specific movements in individuals with recent concussion and those without concussion. The aim was to quantify reaction time between individuals with recent concussion and those without concussion during 3 functional movement tasks designed to simulate common movements on an athletic field: (1) jump landing, (2) anticipated cut, and (3) unanticipated cut. Additionally, we investigated trunk, hip, and knee joint angles at initial ground contact between individuals with recent concussion and healthy control individuals during the same tasks. We hypothesized that individuals with recent concussion would be slower to react, especially as task difficulty increased, and that joint kinematics would differ between the groups.

Methods

Design and setting

We recruited a convenience sample of 30 college-aged recreational athletes. There were 2 groups (15 participants in each group): (1) recent concussion group (median days postconcusssion, 126; range, 28–432d) and (2) matched control group with no recent concussions (matched on sex, age [±1y], mass [±10%], and height [±5%]). One control group participant had suffered from 2 concussions, with the most recent occurring >1,000 days prior to testing. No other control group participants reported any history of concussion (table 1). Participants were excluded for attention deficit hyperactivity disorder, lower extremity injury resulting in physical activity time loss of at least 3 days within the last 6 months, any history of lower extremity or low back surgery, concussion requiring admittance to the hospital, any current concussion symptoms or balance issues, or previous history of >3 concussions. Our institutional review board approved the study, and all participants signed an informed consent document prior to testing.

List of abbreviations:

ANCOVA analysis of covariance
ES effect size
RTP return to participation

Table 1 Group demographics and statistical comparisons

Demographic	Concussion Group (n=15)	Control Group (n=15)	*P*
Age (y)	19.7±0.9	19.7±1.6	.89
Height (cm)	169.2±9.4	172.3±10.8	.41
Mass (kg)	66.0±12.8	71.0±10.4	.25
Female, % (n)	60.0 (9)	60.0 (9)	NA
Male, % (n)	40.0 (6)	40.0 (6)	NA
Median days since concussion (range)	126 (28–432)	NA*	NA
Total concussions*	1 (1–3)	0 (0–2)*	NA

NOTE. All variables are represented by the mean ± SD unless otherwise noted.

Abbreviation: NA, not applicable.

* One control participant had experienced 2 concussions; their most recent concussion was 1103 days prior to testing. No other control participants had a history of concussion. Healthy controls were matched to each injured participant based on sex, age (±1y), mass (±10%), and height (±5%).

Instrumentation

The Vicon System[a] consists of 10 infrared video cameras in conjunction with 2 piezoelectric force platform[b] embedded in the floor. Kinematic data were collected at 150Hz and calibrated for a 4-m-long×3-m-wide×2.5-m-high volume, whereas kinetic data were collected at 1500Hz. The world axis system was established as positive anteriorly in the sagittal plane, left in the frontal plane, and superior in the transverse plane. Each participant was outfitted with 20 individual retroreflective markers affixed to the skin or spandex over the jugular notch, the L5 area of the low back, bilaterally on the acromion process, the anterior-superior iliac spine of the pelvis, the greater trochanter, the medial epicondyle of the femur, the lateral epicondyle of the femur, the medial malleolus, the lateral malleolus, and the first and fifth metatarsal heads. Cluster markers (4 markers on left side, 3 on right side and sacrum) were affixed over the sacrum and bilaterally on each thigh, shank, and foot. After an initial static trial, all individual markers except those at the tip of each shoulder and jugular notch were removed, and the participant completed the testing with the clusters.

Data collection procedures

Participants attended the laboratory for a single session and completed 3 functional movement tasks in a randomized order. Participants were given multiple practice trials for each task until they reported feeling comfortable.

Jump landing

Participants stood on a 30-cm box placed a horizontal distance equal to 50% of their height behind the forceplates. The participants were instructed to take an athletic stance (a self-selected athletic stance they would take to prepare for movement) on the box and await a stimulus to signal the trial start. A visual stimulus (green light) placed approximately 3m in front of the participant was triggered randomly by the principal investigator within 5 seconds of the participant assuming the athletic stance, indicating the trial start. The participant jumped forward off the box and performed a double-leg landing before jumping vertically for maximal height. The participant was instructed to initiate the movement as quickly as possible after the visual stimulus, and completed 5 trials.

Anticipated cut

The setup for the anticipated cut was the same as the jump landing. When the stimulus was provided, the participant jumped forward off the box and landed on a single leg, immediately cutting at a 45° angle through a timing gate in the direction provided by the investigator prior to the trial (cut toward dominant = land on nondominant foot; cut toward nondominant = land on dominant foot; dominant leg was defined as the leg used to kick a soccer ball). Each participant completed 5 trials in each direction.

Unanticipated cut

Procedures for the unanticipated cut were identical to those for the anticipated cut except that the participant was not informed a priori of the direction to cut. As the participant jumped from the box, a timing gate set at .76m behind the forceplates was triggered. This distance was chosen to maximize the time each participant would have to react to the directional stimulus, but be in a position where shorter participants would not be excluded. The timing gate further triggered a visual stimulus (set of blue and green lights) to the participant's left or right, and participants were instructed to cut toward the light. Each participant completed 10 total trials, regardless of whether they were performed correctly, but must have completed at least 1 successful trial to be included in analysis. Trials were considered successful if the participant landed appropriately on a single leg (entire foot on a single forceplate, did not land with 2 feet) and cut in the correct direction.

Data reduction and analysis

All biomechanics data were imported into Motion Monitor v8.0[c] to calculate Euler joint angles. Joint motion was defined as the distal segment moving relative to the proximal segment, except for trunk motion in the frontal and sagittal planes, which was defined as trunk segment movement relative to the vertical axis. Positive in the sagittal plane indicates flexion at the trunk and knee, and extension at the hip. Positive in the frontal plane indicates adduction at the hip, varus angle at the knee, and right lateral trunk flexion. All kinematic data were filtered with a fourth-order low-pass Butterworth filter with a cutoff frequency of 10Hz. Data were then exported to custom MATLAB software[d] to identify all dependent variables of interest.

Reaction time was calculated as follows for all the functional movement tasks. The mean position of the bottom sacral cluster marker in the sagittal and transverse planes was calculated by analyzing 0.5 seconds of data prior to visual stimulus onset. Movement onset was defined as first movement of the bottom sacral cluster marker in either the sagittal or transverse plane exceeding 3cm from the mean marker position prior to the visual stimulus onset. Visual inspection of the data indicated that some participants moved in the sagittal plane first, whereas others first moved in the transverse plane. Therefore, we analyzed both the sagittal and transverse planes to capture first movement after presentation of the visual stimulus. Reaction time was defined as the time in seconds from visual stimulus onset to first movement.

Reaction time cost was calculated as follows:

$$\text{Reaction time cost} = \frac{\left(\text{Reaction Time}_{\text{Jump Landing}} - \text{Reaction Time}_{\text{Cut}}\right)}{\text{Reaction Time}_{\text{Jump Landing}}} \times 100$$

Reaction time cost standardizes participant scores by performance on the simplest task, the jump landing, and may therefore provide useful information regarding the relative change in movement reaction time between tasks of varying demands on neuromuscular control. Negative values for reaction time cost indicate increased reaction time during cutting trials relative to jump landing trials. We initially compared reaction time during anticipated cuts to the dominant and nondominant sides. No differences were observed ($t_{27} = .84$; $P = .410$); therefore, we combined reaction time outcomes for cuts to the dominant and nondominant side. Because 5 jump landing trials were performed, we used the first 5 successfully completed anticipated and unanticipated cuts (out of 10 total trials) when analyzing reaction time and reaction time cost. One participant in each group only completed 1 successful unanticipated cut, whereas 2 participants in the control group completed 4 successful unanticipated cuts. All other participants (n = 26) successfully completed at least 5 unanticipated cuts.

Trunk, hip, and knee joint angles at initial ground contact were calculated in the sagittal and frontal planes during the movement tasks. Initial ground contact was defined as >10N of vertical ground reaction force.[20] Dependent variables for jump landing were reported as angles of the dominant limb. When assessing kinematic outcomes, cuts toward the dominant and nondominant sides were analyzed separately.

To explore reaction time outcomes, we used a 3 (task) × 2 (group) between-subjects mixed-model analysis of covariance (ANCOVA). Bonferroni-corrected *t* tests were used to post hoc test significant interactions or main effects. We used separate between-subjects ANCOVAs to explore kinematic differences for each movement task. We covaried for the number of days between concussion and testing session in all statistical models. Specifically, the number of days postinjury for each concussion group participant was subtracted from the group mean days since concussion (177d); control participants were assigned a value of zero days since concussion. This produced a value representing mean-centered days since concussion, which was used as a covariate in all statistical models. An a priori α value of .05 was established.

Results

There were no significant group demographic differences (see table 1). Reaction time data were not available for 2 concussed group participants because of technical issues with the visual stimulus. Twenty-seven participants successfully completed at least 1

Table 2 Reaction time and RTC during jump landing, anticipated cut, and unanticipated cut, adjusted for days since concussion

Task	Concussion Group	Control Group	P*	ES†
Jump landing	0.517 (0.471 to 0.551)	0.520 (0.482 to 0.557)	.091	.02
Anticipated cut	0.511 (0.471 to 0.551)	0.461 (0.424 to 0.498)		.35
Unanticipated cut	0.569 (0.529 to 0.608)	0.536 (0.499 to 0.573)		.23
Anticipated cut RTC, %	0.82 (−7.29 to 5.65)	10.68 (4.66 to 16.70)	.030	.62
Unanticipated cut RTC, %	−10.06 (−17.50 to 2.62)	−4.97 (−11.90 to 1.95)	.313	.28

NOTE. Values are mean (95% confidence interval) or as otherwise indicated. Data were missing for 2 concussed group participants. RTC calculated as follows: ([Jump landing−Cut]/Jump landing)×100.
Abbreviation: RTC, reaction time cost.
* Mean centered number of days between concussion and testing session was included as a covariate in all statistical models. P value for the 3 movement tasks represents the interaction term in a 3 (task)×2 (group) ANCOVA. P value for the RTC outcomes represents between-group comparison, one for anticipated cut RTC and one for unanticipated cut RTC.
† Calculated as Cohen d.

unanticipated cut toward their nondominant side. Data from all 30 participants were used to investigate all other outcomes.

Reaction time

There were no significant interactions observed for reaction time ($F_{2,52}=2.51$; $P=.091$). We observed a significant main effect for task ($F_{2,52}=15.10$; $P<.001$) such that slower reaction times were observed during unanticipated cuts compared with both anticipated cuts ($P<.001$; effect size [ES], 1.04) and jump landings ($P=.020$; ES, .53). Jump landing reaction times were significantly slower than anticipated cut reaction times ($P=.031$; ES, .50). Group by task reaction time descriptive statistics are presented in table 2.

Reaction time cost

Group differences were observed during anticipated cut ($F_{2,25}=5.26$; $P=.030$) such that the control group reaction time cost (10.7%) improved significantly relative to jump landing, whereas the concussed group (0.8%) did not change. No group differences were observed for reaction time cost during the unanticipated cut ($F_{2,25}=1.06$; $P=.313$). Group by task reaction time cost descriptive statistics and ESs are presented in table 2.

Kinematic outcomes

There were no group differences during the jump landing task ($P\geq.236$). The concussed group displayed significantly greater trunk flexion (27.1°; 95% confidence interval, 24.1°−30.2°) than the control group (22.0°; 95% confidence interval, 18.9°−25.1°) when cutting toward the nondominant side during the anticipated cutting task ($F_{2,27}=5.89$; $P=.022$). No other comparisons were statistically significant ($P\geq.079$). Jump landing, anticipated cutting, and unanticipated cutting outcomes and ESs are presented in tables 3−5.

Discussion

Functional assessments of dynamic movements are not a part of the recommended concussion assessment battery.[21,22] However, reports of dynamic balance deficits,[6,7,23] cortical hypoexcitability,[17,18] lower extremity stiffness alterations,[19] and increased risk of musculoskeletal injury[9-14] suggest that there may be neuromuscular control effects secondary to concussion that persist beyond RTP. We hypothesized that individuals with recent concussion would be slower to react, especially as task difficulty increased, and that joint kinematics would differ between the groups. The findings from this preliminary study suggest there may be differences in reaction time and trunk control during sport-like dynamic movement. Concussed participants tended to be more flexed at the trunk during cutting tasks (ES between .32 and .63; mean difference, 2.5°−5.1°); however, this was only a statistically significant difference during the anticipated cut to the nondominant side. When standardizing for reaction time during our simplest task, we observed significantly improved reaction time cost during anticipated cut for the control group compared with the concussed group (ES, .62).

Table 3 Trunk, hip, and knee angles at initial ground contact for each group during jump landing, adjusted for days since concussion

Jump Landing*	Concussion Group	Control Group	P	ES†
Trunk flexion (deg)	28.5 (25.0 to 32.0)	25.6 (22.2 to 29.1)	.236	.31
Trunk right lateral flexion (deg)‡	0.1 (−0.7 to 1.0)	−0.1 (−1.0 to 0.7)	.651	.12
Hip flexion (deg)	−32.4 (−37.5 to −27.2)	−33.9 (−39.0 to −28.7)	.680	.11
Hip abduction (deg)	−8.9 (−11.6 to −6.3)	−7.9 (−10.6 to −5.3)	.596	.14
Knee flexion (deg)	27.0 (23.7 to 30.3)	26.9 (23.5 to 30.2)	.956	.01
Knee varus (deg)	1.8 (−0.8 to 4.4)	1.4 (−1.2 to 4.0)	.823	.06

NOTE. Values are mean (95% confidence interval) or as otherwise indicated. Positive in the frontal plane indicates adduction at the hip, varus angle at the knee, and right lateral trunk flexion.
* Angles at hip and knee are calculated for each participant's dominant side.
† Calculated as Cohen d.
‡ A negative value indicates trunk lateral flexion to the left side. Positive in the sagittal plane indicates flexion at the trunk and knee, and extension at the hip.

Table 4 Trunk, hip, and knee angles at initial ground contact for each group during anticipated cut, adjusted for days since concussion

Anticipated Cut	Concussion Group	Control Group	*P*	ES*
Dominant cut†				
Trunk flexion (deg)	26.9 (24.2 to 29.6)	23.5 (20.8 to 26.2)	.079	.47
Trunk right lateral flexion (deg)‡	−0.2 (−2.0 to 1.6)	−0.5 (−2.2 to 1.3)	.819	.06
Hip flexion (deg)	−21.0 (−24.8 to −17.3)	−21.1 (−24.9 to −17.4)	.965	.01
Hip abduction (deg)	−16.5 (−20.4 to −12.6)	−15.3 (−19.2 to −11.3)	.648	.12
Knee flexion (deg)	11.8 (9.5 to 14.1)	12.1 (9.8 to 14.4)	.855	.05
Knee varus (deg)§	−0.5 (−2.8 to 1.7)	−1.0 (−3.3 to 1.2)	.763	.08
Nondominant cut‖				
Trunk flexion (deg)	27.1 (24.1 to 30.2)	22.0 (18.9 to 25.1)	.022	.63
Trunk right lateral flexion (deg)	0.0 (−1.3 to 1.4)	1.7 (0.3 to 3.0)	.087	.46
Hip flexion (deg)	−18.3 (−22.5 to −14.1)	−18.9 (−23.1 to −14.7)	.844	.05
Hip abduction (deg)	−19.1 (−23.2 to −15.0)	−15.3 (−19.4 to −11.2)	.191	.35
Knee flexion (deg)	11.7 (9.1 to 14.2)	11.1 (8.6 to 13.7)	.762	.08
Knee varus (deg)§	0.7 (−1.9 to 3.2)	−2.2 (−4.8 to 0.3)	.115	.23

NOTE. Values are mean (95% confidence interval) or as otherwise indicated. Positive in the frontal plane indicates adduction at the hip, varus angle at the knee, and right lateral trunk flexion.

* Calculated as Cohen *d*.

† Indicates a cut toward the dominant side, executed by planting on the nondominant foot.

‡ A negative value indicates trunk lateral flexion to the left side.

§ A negative value indicates knee valgus.

‖ Indicates a cut toward the nondominant side, executed by planting on the dominant side. Positive in the sagittal plane indicates flexion at the trunk and knee, and extension at the hip.

This study was intended to be a preliminary investigation with the goal of informing the design of larger studies that include baseline preinjury measures and serial measures throughout recovery. Our findings were largely in contrast with those observed by Lapointe et al,[24] who reported decreased knee varus and external rotation during a jump cut maneuver in individuals with previous concussion (mean time since concussion, 3.1y) compared with controls. Although it is unclear why our findings contrasted, several potential reasons include different cutting protocols, different sample sizes (19 in Lapointe,[24] and 30 in this investigation), and different postinjury assessment time points (3.1y in Lapointe,[24] and 126d in this investigation). Although we observed differences in trunk flexion during anticipated cutting, the clinical implications of the observed differences remain unclear. Trunk flexion has been associated with sagittal and transverse plane knee motion and loading,[20,25,26] and control of trunk movement during landing and cutting has been suggested as an important component of injury prevention programs.[20,25,26] Our findings provide

Table 5 Trunk, hip, and knee angles at initial ground contact for each group during unanticipated cut, adjusted for days since concussion

Unanticipated Cut	Concussion Group	Control Group	*P*	ES*
Dominant cut†				
Trunk flexion (deg)	26.0 (23.2 to 28.9)	23.3 (20.4 to 26.1)	.175	.36
Trunk right lateral flexion (deg)‡	−0.2 (−2.3 to 2.0)	−1.9 (−4.0 to 0.3)	.263	.30
Hip flexion (deg)	−15.8 (−19.7 to −11.9)	−18.1 (−22.0 to −14.2)	.404	.22
Hip abduction (deg)	−17.5 (−21.4 to −13.5)	−17.6 (−21.5 to −13.7)	.961	.01
Knee flexion (deg)	10.8 (8.2 to 13.4)	10.2 (7.6 to 12.8)	.755	.08
Knee varus (deg)§	−1.2 (−3.4 to 1.1)	−1.5 (−3.8 to 0.8)	.833	.06
Nondominant cut‖				
Trunk flexion (deg)	26.5 (23.5 to 29.5)	24.0 (20.9 to 27.1)	.234	.32
Trunk right lateral flexion (deg)	1.7 (−1.1 to 4.5)	0.8 (−2.1 to 3.7)	.645	.12
Hip flexion (deg)	−16.1 (−20.6 to −11.6)	−17.0 (−21.7 to −12.4)	.765	.08
Hip abduction (deg)	−20.6 (−24.4 to −16.9)	−16.5 (−20.4 to −12.6)	.130	.42
Knee flexion (deg)	11.5 (8.4 to 14.6)	11.8 (8.5 to 15.0)	.896	.03
Knee varus (deg)§	0.6 (−2.3 to 3.5)	−2.5 (−5.5 to 0.5)	.139	.24

NOTE. Values are mean (95% confidence interval) or as otherwise indicated. Positive in the frontal plane indicates adduction at the hip, varus angle at the knee, and right lateral trunk flexion.

* Calculated as Cohen *d*.

† Indicates a cut toward the dominant side, executed by planting on the nondominant foot.

‡ A negative value indicates trunk lateral flexion to the left side.

§ A negative value indicates knee valgus.

‖ Indicates a cut toward the nondominant side, executed by planting on the dominant side. Twenty-seven participants completed unanticipated cuts toward the nondominant side. Positive in the sagittal plane indicates flexion at the trunk and knee, and extension at the hip.

some evidence that neuromuscular control may be altered after concussion, which is consistent with 2 previous investigations aimed at understanding lower extremity joint stiffness[19] and movement after concussion.[24] However, the preliminary nature of our study along with our lack of significant findings for many outcomes does not allow us to draw comprehensive conclusions about potential neuromuscular control alterations postconcussion.

Longitudinal assessment of reaction time using laboratory tasks that simulate sport-specific conditions may be an important consideration in elucidating the mechanisms behind the increased musculoskeletal injury risk after concussion.[9,11-14] Traditionally, reaction time (ie, cognitive processing speed) is assessed after concussion as part of a neurocognitive test battery. Many computerized cognitive tests assess reaction time by adapting traditional neuropsychological tests (eg, Stroop task, symbol matching). These measures are sensitive to concussion in the acute phase of the injury.[27,28] Whether postconcussion deficits in cognitive processing speed on neuropsychological tools manifest in more functional activities (eg, a delayed movement response during competitive sports) is not clear. A more functional reaction time measure, involving the individual with a concussion catching a stick as quickly as possible after it is released, has demonstrated sensitivity to acute concussion reaction time deficits.[29-31] Although this is a valid and clinician-friendly tool to assess reaction time, this measure is very simplistic, and does not present athletes with the requisite challenge to mimic the on-field stimuli for which they will need to respond once they RTP. It remains unclear how these simplistic reaction time measures correlate to the reaction time required to appropriately respond to external stimuli during sport activity. We observed reaction time cost between group differences during the anticipated cut, but did not see any group differences when exploring reaction time alone. Reaction time cost standardizes reaction time for each participant based on reaction time during the simplest movement task, potentially making this measure more sensitive to reaction time changes at the individual level. The mechanism behind our observed group differences is unclear, but may reflect slowed cognitive processing in individuals with previous concussion. Cognitive processing issues may be more apparent in dual-task situations (combined cognitive and motor tasks), such as the procedures used here and in various investigations of gait after concussion.[7,8,32] Traditional reaction time testing as previously described is usually done with emphasis on the cognitive contributions while minimizing movement (ie, a finger depressing a mouse button in response to a cognitive stimulus).

We developed novel methods to explore functional reaction time in this study. A classic study by Henry and Rogers[33] details the influence of task complexity on reaction time. In short, as overall task difficulty increases, so does reaction time. We hypothesized reaction times would be slowest during our most difficult motor task, the unanticipated cut, and fastest during the easiest task, the jump landing. Our hypothesis was partially supported, but participants demonstrated faster reaction times during anticipated cutting compared with jump landing. The slower reaction times during jump landing may be explained by the task being too simple. Several studies reveal better balance control (less and slower postural sway) when a simple cognitive task is added to a balance task instead of the balance task alone.[34-36] If the balance task is simple enough, participants often perform better when their attention is diverted away from the relatively simple act of maintaining postural control. Movement reaction time may be similarly influenced by attention demand. Participants may have focused their attention on the reaction time component of the jump landing because the motor task was simple. Therefore, it is plausible reaction time may actually have been degraded because of increased attentional demand. In contrast, attention may have been diverted to the motor portion of the anticipated cutting task, making the reaction portion of the movement more reflexive.

Study limitations

Although our study is among the first to examine functional movement outcomes postconcussion, it is important to note that we did not observe significant group differences for most of our kinematic comparisons. There are several possible explanations for the lack of group differences. First, our concussed group was, on average, 4 months postinjury (median time since concussion, 126d; range, 28−432d) when we assessed their movement. If movement differences are present more acutely after concussion and resolve within a few months, then our wide-ranging postconcussion window may be diluting the effect. Second, our relatively small sample may have limited statistical power and increased our chances of making a type II error (failure to observe a difference that exists between the 2 populations); however, we do report statistical differences for 2 of our outcomes. Two participants (1 in each group) only completed a single successful unanticipated cut trial. In these 2 cases, a single trial may not accurately depict normative movement during the unanticipated cut for these participants.

Further study of the recovery trajectory of neuromuscular control deficits postconcussion, and their influence on injury rates after RTP, is warranted. Future research in this area involves the development of new research paradigms for assessing movement control deficits under sport-specific conditions. Reaction time should be explored further after concussion during dynamic movements (eg, countermovements, multiple cutting tasks, jump/cut combination tasks). Future studies should quantify differences between static and dynamic reaction time assessments, along with single- and dual-task reaction time protocols, to ensure clinicians are appropriately assessing functional reaction time deficits after concussion. Influencing reaction time by manipulating task difficulty may have implications for assessing and rehabilitating concussion.

Conclusions

This study suggests that, during sport-related movement tasks, there may be subtle reaction time and trunk control differences between individuals with recent concussion and healthy individuals. The lack of group differences for most outcomes, however, suggests that movement control deficits, if they exist after concussion, may resolve within a few months.

Suppliers

a. Vicon Motion Capture System; Vicon Motion Systems.
b. Model 4060-NC; Bertec.
c. Motion Monitor v8.0; Innovative Sports Training.
d. MATLAB, version R2016a; MathWorks.

Keywords

Mild traumatic brain injury; Rehabilitation

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