Motor Deficits in Youth with Concussion History: Issues with Task Novelty or Task Demand?

Authors

Marc Dalecki[1], Jessica Usand[1], Arend W. A. Van Gemmert[1], Lauren E. Sergio[2]

Affiliations

1 School of Kinesiology, Louisiana State University, Baton Rouge, United States

2 School of Kinesiology and Health Science, York University, Toronto, Canada

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Correspondence

Marc Dalecki

School of Kinesiology, Louisiana State University

71 Huey P Long Field House

70803-2804 Baton Rouge

United States

Tel.: + 1225 578 6087, Fax: + 1225 578 3680

mdalecki@lsu.edu

ABSTRACT

The present study expands previous work on eye-hand decoupling deficits in youth with concussion history. It examines whether deficits can be linked to difficulties adapting to new task constraints or meeting ongoing task demands. Data from 59 youth with concussion history (M = 11 months post-concussion) and 55 no history controls were analyzed. All 114 participants (M = 12.5 yrs.) performed two touchscreen-based eye-hand coordination tasks: A standard task with vision and motor action in alignment, and an eye-hand decoupling task with both spatially decoupled, with twenty trials per task condition. First (trial 1–4), middle (trial 9–12), and last (trial 17–20) trial blocks were analyzed in each condition across groups, as well as first and last blocks only. The latter analysis showed in the first block longer response times in the concussion history group in the eye-hand decoupling condition due to a general slowdown of the reaction times across blocks and a trend for higher movement times. Our findings suggest that youth with concussion history have difficulty to adapt to new task constraints associated with complex skill performance during a short series of trials. These results are relevant for athletic trainers, therapists and coaches who work with youth with concussion history.

Introduction

Sport-related concussion in youth high school athletics is a common injury and occurs in about 1 out of 20 players per season, in particular, in contact-sports [1]. Two crucial aspects to post-concussion management are i) to provide a safe return to play and ii) to avoid long-term risks after the player returns to game play. A growing number of studies from the past decade support the notion that the return to play timepoint based on current metrics (typically 15–30 days post-concussion in youth) [2] precedes the recovery of complex brain functions needed for successful performance. For example, visually-guided pointing has been shown to deteriorate in young adults tested between one week and more than a year post-concussion compared with age-matched controls with no history of concussion [3]. Also, brain activity changes (e. g. a lower P3 amplitude) have been found in children, adolescents, and young adults six months post-concussion when compared to no-history age-matched controls [4]. Furthermore, it takes youth players more time than adults to recover from a concussion and to return on the field compared to young adults [5], which is not surprising when considering that the youth brain is still developing [6, 7].

In line with these findings, previous work has shown prolonged eye-hand coordination deficits in youth with concussion history for up to 1.5 years post-concussion when participant's performed a challenging cognitive-motor task that required a decoupling of eye and hand movement direction [8, 9]. Importantly, all of the young athletes involved in these studies had already returned to game play after their concussion, in accordance with the current return to play protocols at the time the concussion-incident occurred [10]. Notably, other studies reported a larger risk of re-injury during the first 12 months post-concussion in youth contact-sport players [11, 12]. These observations may provide some insight into why seemingly healthy players who returned to play after a few weeks or months had a higher injury risk. Their brain and their visuomotor system may perform less well during complex tasks – as often required during sports activities – but perform well during simple motor tasks that are used in return-to-play measures [8, 9].

To enhance our understanding of the sources and potential consequences of insufficient sensitive post-concussion performance metrics, motor skill behavior of young athletes affected by concussion needs to be examined in more detail. Specifically, knowledge whether the eye-hand coordination deficits, as reported in the latter two studies, are consistent throughout performance or change during a series of trials would prove useful in practice. Consistently poor performance would suggest a global coordination problem for demanding skills requiring cognitive-motor integration. Alternatively, poor performance at the beginning of the novel, rule-based movement task (but which improves over the course of trials) would suggest a difficulty in adapting to a novel skill, but intact global coordination [13]. Thus it would be more a motor adaptation deficit than a basic motor control deficit. Adapting to new task constraints is a situation that is quite common on sports field (e. g. throwing to the left while looking and/or running to the right) [14], and problems within this area could result into a higher risk for being tackled or running late causing to be hit. Another situation occurs when poor performance is observed at the end of a series of tasks suggesting difficulties to maintain attentional focus during a complex skill. In addition, eye-hand coordination deficits occurring during ongoing task performance could be linked to fatigue due to cognitive-motor overload [15]. All of these scenarios could contribute to a higher risk of re-injury in youth athletes following concussion.

Knowing which aspect of motor performance is most affected following concussion will give athletes and their caregivers (such as athletic trainers, coaches, therapists, and parents) a better idea how to minimize re-injury potential. Moreover, it will increase awareness for critical task periods when players are performing complex motor skills during or after recovery from (sport-related) concussion. Therefore, the present study investigated whether motor performance differences between youth with concussion history and controls with no-history may also differ across a series of challenging eye-hand decoupling task trials and simple motor task trials. We expect group differences to be larger rather at the start of the series of trials (i. e. issues with adapting to a novel task) or at the end of the series of trials (i. e. issues with fatigue, attention, and/or task demands). We also expected that this effect occurs in a complex eye-hand decoupling task condition rather than in a simple standard task condition with eye and hand movement directions aligned, since previous work reported deteriorated performance in youth with concussion history, in particular, in the decoupled task.

Materials and Methods

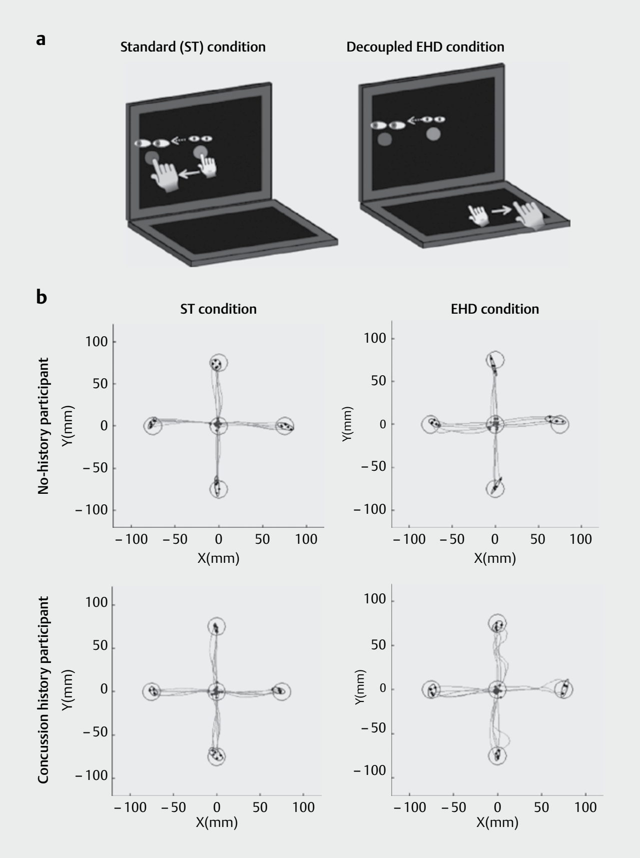
Participants

We re-analyzed data from 114 youth participants who were already part of previous studies [8, 9]. The present data set included 59 participants with a history of sport-related concussion (13.00 ± 1.82 yr; 29 females) and 55 control participants with no history of concussion (12.04 ± 1.89 yr; 23 females). In participants with a history of concussion, the last concussion was on average 10.52 ± 9.19 months prior to the experimental testing (range: 0.25 - 30 months). Demographic data and details of concussion history were obtained using established questionnaires (SCAT3, Child-SCAT3), and participants, parents, team managers and coaches were interviewed to obtain precise and detailed concussion history information. Details for each participant are summarized in the table presented in **Supplementary file I**. Note that at the time of testing, all participants were reported to be healthy and were not diagnosed with a current concussion; participants with concussion history were defined as 'asymptomatic' in accordance with current return-to play protocol guidelines at that time [10, 16], and were fully participating in their team sport. Concussion history and control participants were recruited from the same hockey, soccer, and lacrosse teams. The study protocol was approved by the Human Participants Review Sub-Committee of York University's Ethics Review Board, and conformed to the standards of the Canadian Tri-Council Research Ethics guidelines. The study also met the standards for ethics in sport and exercise science research [17]. Parents and children/adolescents signed written informed consent/assent forms before participating in this study.

Procedures

Participants performed two visuomotor transformation tasks. They slid their index finger of their dominant hand along an Acer Iconia 6120 laptop computer, which has two touchscreens, one in the vertical and one in the horizontal plane. Participants slid their finger along the touchscreen from a central home target to different peripheral targets in two different conditions. In a standard visuomotor mapping task (condition ST), spatial location of the viewed target and the required movement were in alignment (i. e. hand movements were made on the vertical screen directly to visual targets) (cf. ▶ **Fig. 1a**, left graph). In an eye-hand decoupling task (condition EHD) targets were again viewed on the vertical touchscreen, but participants slid their finger along 1) the horizontal touchscreen, and 2) the cursor on the vertical screen moved in the opposite direction than finger movement on the horizontal touchscreen. That is, to move the cursor to the left, they had to slide their finger to the right, etc. That means, there was a decoupling between vision and action in two ways, a plane change and a feedback reversal (cf. ▶ **Fig. 1a**, right graph).

In both conditions, trials were presented in a pseudo-randomized order. The peripheral targets presented on the vertical touchscreen were of 20 mm diameter, red colored and presented to the left, right, above or below the central target (also 20mm in diameter). The distance between the centers of the peripheral and central target (i. e. the screen center) was 75 mm. The task itself was displayed on a 170 × 170 mm black square with the surrounding background colored grey, in order to maintain a constant visual border. There were a total of 20 trials (i. e. 5 to each peripheral target) per condition, thus, altogether 40 test trials per participant. The order of the ST and EHD conditions was randomized across participants in each group. In the present manuscript, we analyzed the first trial block (trial 1–4, one trial to each direction) and last trial block (trial 17–20, also one trial to each direction). The detailed trial timing is presented in the **Supplementary file II**. In short, for the ST condition, a center target was presented on the vertical touchscreen, participants touched the target with the index finger,



▶ **Fig. 1** **a** Schematic description of the experimental tasks. In a standard task with direct goal interaction (condition ST, **left graph**), participants slid their finger on a touchscreen to move a cursor from a central target to one of four peripheral targets. In the cognitive-motor integration task (condition EHD, **right graph**), targets were in a different plane from hand motion, and feedback was reversed 180 ° (i. e. there was a decoupling between viewed target location and hand motion). In each trial, a peripheral target was presented either at the top, right, bottom, or left of a central target. **b** Typical full hand path data of two participants, aged twelve and thirteen years, performing the ST and EHD condition: One participant with no history of concussion (top graphs), and one with concussion history (bottom graphs). Note the poorer hand path of the participant with concussion history when compared to the other participant in the EHD condition for a few but not for all trials.

a peripheral target appeared and the center target disappeared, serving as the 'go-signal' for participants to slide their index finger along the touchscreen to move the cursor to the target. Participants kept their finger within the target until the center target appeared again, and they slid the finger back to the center target, awaiting the next peripheral target. The sequence was the same for the EHD condition, but participants moved their finger along the horizontal touchscreen in the opposite direction of the presented target to move the cursor on the vertical screen. Participants were instructed to move as quickly and accurately as possible, and ambient distractions were kept to a minimum. Participants had full vision of their hand and fingers, and were instructed to always look towards the targets presented on the vertical screen and not to their hand. The experimenter provided a verbal explanation for both task conditions before each condition started and monitored participant's eye movements during the experiment. If incorrect movements were made, participants were reminded to look towards the target and not to their hand. Incorrect movements were eliminated before final data analysis.

Data processing

Details of the data processing are also provided in the **Supplementary file II**.

Dependent measures

In the current study, we focused on variables that reached statistical significance between groups (Concussion history, No-history) in previous studies, i. e. movement time (MT) and path length (PL) [8]. In addition, we added response time (RespT) and reaction time (RT), since both variables provide further insight into MT and PL and their potential relationships. For each trial, RT was calculated as the time between disappearance of the central target and movement onset, i. e. when the participant began the movement execution and started to slide the cursor towards the target. MT was calculated between movement onset and final movement endpoint (i. e. reaching the peripheral target). RespT was calculated as the sum of RT and MT. PL was calculated as the cumulative distance travelled between start and end location of the movement. Movements comprised of curves or deviations from a straight path between the central and peripheral target would thus result in a longer path length.

Statistical analysis

Visuomotor task performance

In order to elucidate performance changes across task time, we calculated the mean values and standard deviation (i. e. variability) across the first (trial 1–4), third (trial 9–12) and fifth trial block (trial 17–20), for both groups (Concussion history, No-history) and both conditions (ST, EHD). For all dependent measures (RespT, RT, MT, PL), we analyzed the effects of group (Concussion history, No-history), block (1, 3, 5), and condition (ST, EHD), using a repeated-measures mixed 2 × 3 × 2 ANOVA, with the factors condition and block as within-subjects factor and the factor group defined as the between-subjects factor. In addition, an ANCOVA was performed with sex and time since concussion as covariates. In order to focus on the main aim of the study (does novelty and/or fatigue exacerbate performance deterioration effects) and to increase statistical power, we finally performed a 2 × 2 × 2 ANOVA, which focused on block 1 (i. e. the first block) and block 5 (i. e. the last block) only. When significant main or interaction effects were observed, post-hoc comparisons were performed and adjusted for multiple comparisons (Bonferroni). All data were checked for normal distribution (Shapiro-Wilk's test) and sphericity (Mauchly's test) and were Greenhouse-Geisser corrected in case of sphericity violations. All statistical analyses were performed using SPSS statistical software (IBM Inc.). Statistical significance levels were set to $\alpha < 0.05$.

Results

Mean performance results in both groups across blocks and task conditions

For the 2 × 3 × 2 ANOVA that included blocks 1, 3, and 5, the mean results (average score within blocks 1, 3, and 5), the descriptive results are summarized in ▶ **Table 1**, and the test statistics are summarized in ▶ **Table 2**. ANOVA revealed a significant main effect for RT ($p < 0.05$), showing a general larger RT in the concussion history group, and a significant group × condition interaction for PL ($p < 0.05$), revealing PL being larger in the concussion history group compared with the no-history group only in the EHD but not in the ST condition ($p < 0.05$). Independent of group and condition, significant main effects of block were shown for RespT ($p < 0.001$), RT ($p < 0.01$), and MT ($p < 0.01$), but not for PL ($p > 0.05$), denoting overall performance changes across task time for RespT, RT, and MT. Notably, these performance changes across blocks showed different patterns across conditions (ST, EHD) and groups (Concussion history, No-history). In the EHD condition, the concussion history group improved performance from the first to the last block (RespT $p < 0.001$; RT and MT both $p < 0.01$), whereas the No-history control performance group remained on the same level (all $p > 0.05$) (cf., ▶ **Fig. 2 a–c**).

In contrast, in the ST condition, the no-history controls improved performance from the first to the middle and last block (RespT and MT, both $p < 0.05$), a pattern which was absent in the concussion history group, whose performance remained consistent across all three blocks within the ST condition (all $p > 0.05$) (cf., ▶ **Fig. 2 d–f**).

We did not find a significant three-way interaction between group × block × condition for any variable with the analysis across three blocks (all $p > 0.05$). In addition, the ANCOVA analysis with the covariates sex and time since last concussion did not reveal significant effects on the dependent outcome measures (all $p > 0.05$).

For the 2 × 2 × 2 ANOVA (with block 1 and 5 only), descriptive results are again presented in ▶ **Table 1**, and test statistics are summarized in ▶ **Table 3**. Notably, ANOVA revealed a significant three-way interaction for condition × block × group for RespT and MT (both $p < 0.05$). Pair-wise comparisons revealed for RespT a significant difference between groups in the EHD condition for block 1($p < 0.05$) but not for block 5 ($p > 0.05$), and no group differences in condition ST in either block (all $p > 0.05$). Thus, RespT deficits in youth with concussion history were limited to block 1 in condition EHD. This finding was mirrored for MT. Pair-wise comparisons revealed for MT a trend for a group effect in block 1 of the EHD condition only ($p = 0.08$), MT difficulties tended to be present in youth with concussion history only in block 1 of condition EHD. Similar than in the first analysis, ANOVA revealed a significant main effect of group for RT and PL (both $p < 0.05$), revealing an overall increased RT and PL over time for block 1 and 5 in the concussion history group.

Performance variability in both groups across blocks and conditions

Performance variability (i. e. the standard deviation within the blocks) failed to show significant effects for group, block, block × group, and block × group × condition for RespT, RT, MT, and PL (all $p > 0.05$). Thus, it can be concluded that movement variability did not differ between youth with a history of concussion and controls.

In summary, we found time-related group differences between concussion history and no-history controls in the eye-hand decoupling EHD condition. Youth with concussion history had a longer response time during the first block in the EHD condition when compared with the last block, likely driven by a trend for a longer movement time and overall longer reaction time, independent from condition and block. Similar as reaction time, the concussion history group's spatial movement execution (i. e. path length) was elongated across the analyzed blocks and condition as well.

▶ **Table 1** Mean descriptive results of the repeated-measures mixed ANOVA with group (Concussion history, No-history), block (Trial 1-4, Trial 9-12, Trial 17-20), and condition (ST, EHD). Abbreviations: RespT = Response time, RT = Reaction time, MT = Movement time, PL = Path length; ST = Standard, EHD = Eye-hand decoupling; SD = Standard Deviation.

		Condition ST				**Condition EHD**			
Variable	**Block**	**Concussion history**		**No-history**		**Concussion history**		**No-history**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
[ms]									
RespT	Trial 1-4	983.31	333.72	961.51	346.11	1868.50	705.11	1597.84	538.73
	Trial 9-12	953.70	398.39	870.52	233.68	1727.31	604.23	1526.46	468.55
	Trial 17-20	937.94	337.78	852.57	203.17	1594.10	576.22	1487.42	530.36
RT	Trial 1-4	465.32	176.31	426.10	252.11	638.54	229.35	573.62	151.16
	Trial 9-12	440.30	159.18	404.25	133.28	636.01	270.53	549.11	149.82
	Trial 17-20	436.00	141.54	395.20	113.61	571.98	175.69	531.47	152.21
MT	Trial 1-4	517.99	262.21	535.40	223.89	1229.96	578.64	1024.22	516.63
	Trial 9-12	513.40	297.99	470.45	185.09	1091.30	472.83	996.61	441.52
	Trial 17-20	501.94	257.22	457.37	187.45	1022.12	516.23	955.95	482.87
[mm]									
PL	Trial 1-4	72.30	4.06	72.27	4.76	81.94	22.80	76.18	13.54
	Trial 9-12	72.40	2.95	71.84	2.81	80.70	18.57	74.28	10.50
	Trial 17-20	73.00	8.26	71.23	3.50	81.56	20.70	75.60	12.46

▶ **Table 2** Mean results for statistical outcomes of the repeated-measures mixed ANOVA of group (concussion history, no-history), block (1, 3, 5), and condition (ST, EHD) for all dependent variables (RespT, RT, MT, PL). Abbreviations: ConcHist = Concussion History, No-Hist = No History; RespT = Response time, RT = Reaction time, MT = Movement time, PL = Path length; ST = Standard condition, EHD = Eye-hand decoupling; η^2 = partial eta square.

variable	**group**			**block**			**condition**			**group × block**		
	(ConcHist, No-Hist)			**(1, 3, 5)**			**(ST, EHD)**					
	F (1,108)	**p - value**	**η^2**	**F (2,216)**	**p - value**	**η^2**	**F (1,108)**	**p - value**	**η^2**	**F (1,108)**	**p - value**	**η^2**
RespT	3.662	0.058	0.033	12.055	0.000	0.100	349.686	0.000	0.764	0.505	0.604	0.005
RT	4.744	0.032	0.042	5.255	0.006	0.046	94.337	0.000	0.466	0.319	0.728	0.003
MT	1.783	0.185	0.016	6.813	0.001	0.059	312.690	0.000	0.743	0.301	0.740	0.003
PL	6.967	0.010	0.061	0.399	0.671	0.004	27.655	0.000	0.204	0.125	0.882	0.001

variable	**group × condition**			**block × condition**			**group × block × condition**			
	F (1,108)	**p - value**	**η^2**	**F (2,216)**	**p - value**	**η^2**	**F (2,216)**	**p - value**	**η^2**	
RespT	2.923	0.090	0.026	2.301	0.103	0.021	2.229	0.110	0.020	
RT	0.630	0.429	0.006	1.227	0.295	0.011	0.649	0.524	0.006	
MT	2.488	0.118	0.023	1.592	0.206	0.015	2.268	0.106	0.021	
PL	4.964	0.028	0.044	0.251	0.779	0.002	0.100	0.905	0.001	

Discussion

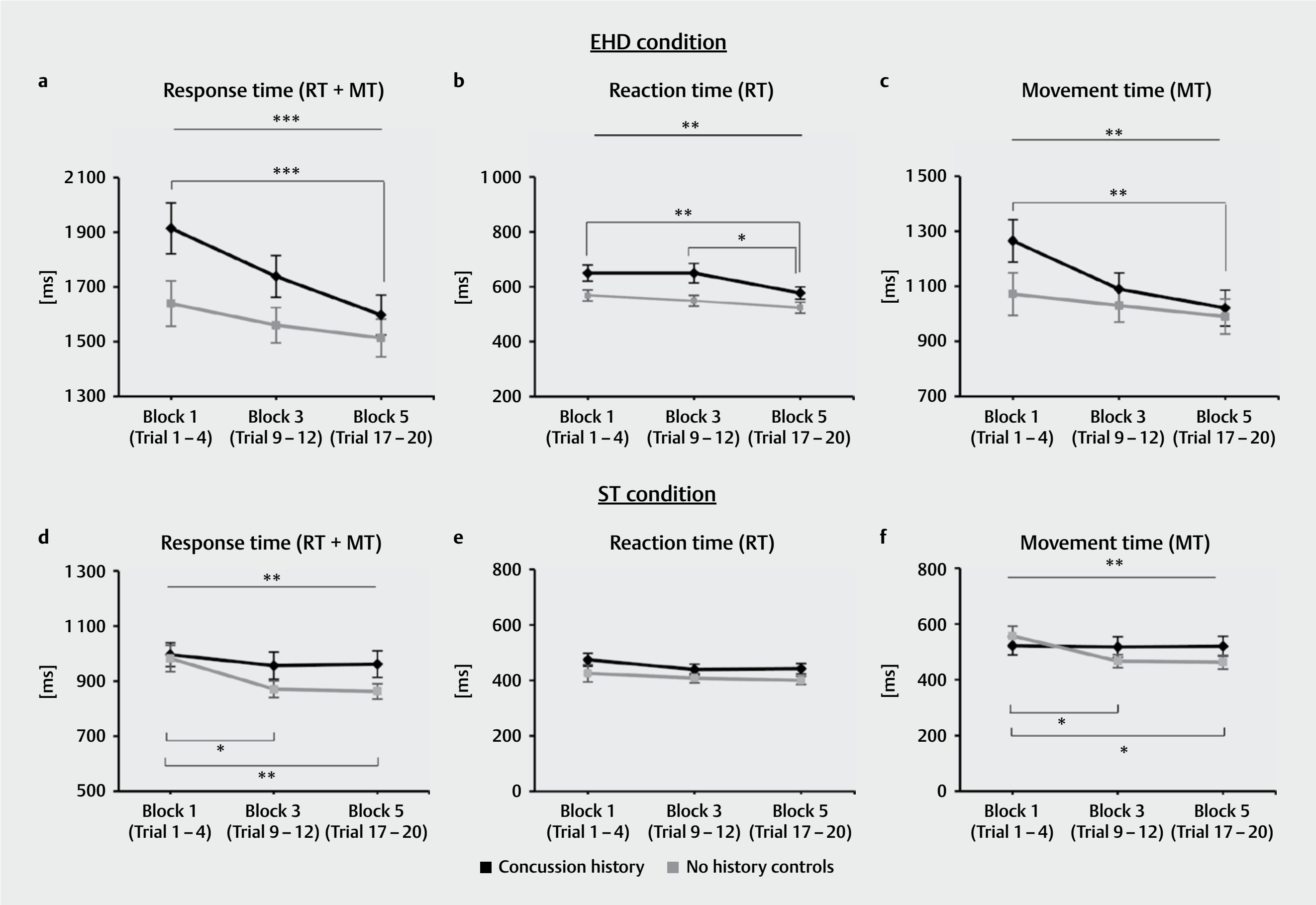
The present study examined whether previously found eye-hand coordination performance deficits in youth with a history of concussion alter across time over a short series of task trials. Notably, we found that youth with concussion history performed worse at the start of the series of twenty trials in a challenging eye-hand decoupling (EHD) task as compared to performance of no-history controls. In the EHD condition, during the first four trials, concussion history participants had a longer response time and tended to require more time to execute the movement (i. e. longer movement times). Response time and movement execution differences between both groups in the EHD condition disappeared when more trials were performed. Ultimately, this decrease in difference between the two groups in condition EHD resulted in similar response and movement times in the last block (see ▶ **Fig. 3 a–c**) and middle block (cf., ▶ **Fig. 2 a–c**, ▶ **Tables 1**, **2**).

Our current findings support the notion that youth with a history of concussion, even on average 1.5 years post-event, also have deficits with their capability to adapt to novel task constraints linked to complex eye-hand decoupling. One possible explanation is that spatial-visual cues are known to be more critical earlier rather than later during the learning of new movement tasks (Fleishmann & Rich 1963), and that a spatial discordance between eye and hand involves higher cognitive processes to correct the misalignment (Redding 1993). Indeed, the feedback reversal during the EHD task condition requires executive function processes linked to inhibition, since the frontal lobe has to inhibit the naturally aligned eye- and hand movement direction [18, 19]. These data suggest that one cognitive aspect of the problems with the neural control of complex movement in the previously concussed youth may have been one of inhibition control, since to implement this complex spatial sensorimotor integration required inhibitory functions. Inhibitory control is indeed known to be a critical component in youth post-concussion [20], as well as for increased cognitive demand [21, 22]. Supporting this suggestion, the time-related EHD deficits in the concussion history group were limited to temporal (i. e. response and movement times) aspects of movement control, while temporal planning (i. e. reaction time) and spatial characteristics of the movement execution (i. e. path length) were deteriorated across the analyzed trials but were unaffected by time and condition. Notably, the performance of the no-history controls did not change across blocks in the EHD task condition, suggesting adaptation to novel eye-hand skills requiring the inhibition of naturally-aligned body motions can occur quickly in the studied age group.

The present findings combined with previous discoveries [8] may partially explain why youth who returned to game-play after a concussion are at a higher risk of incurring another concussion or injury within the first year post-injury [11, 12]. In previous studies, it was shown that lingering eye-hand decoupling deficits remained present for much longer than previously expected in both asymptomatic youth [8, 9] and asymptomatic elite athletes [14] who had all returned to play. In the present study, we expand on these findings with details about the time course of EHD deficits in youth with concussion history to include task demand. Eye-hand decoupling is an important and common skill on the sport-field, in particular, in popular contact sports such as American football, lacrosse or hockey [23].

Pronounced eye-hand decoupling deficits in youth with concussion history during the initial start of task performance, such as the presently reported slower response times, may increase the risk of the player to be tackled or to get hit [24, 25]. Thus, in addition to a generally decreased performance level, these players may have an increased injury risk [26–28] due to the extra temporal delay when participants have to adapt to novel task constraints. Therefore, the current findings might provide practical implications for coaches, athletic trainers, and athletes; it provides useful information about focus on specific skill interventions after or during the recovery from a recent concussion in youth athletes.

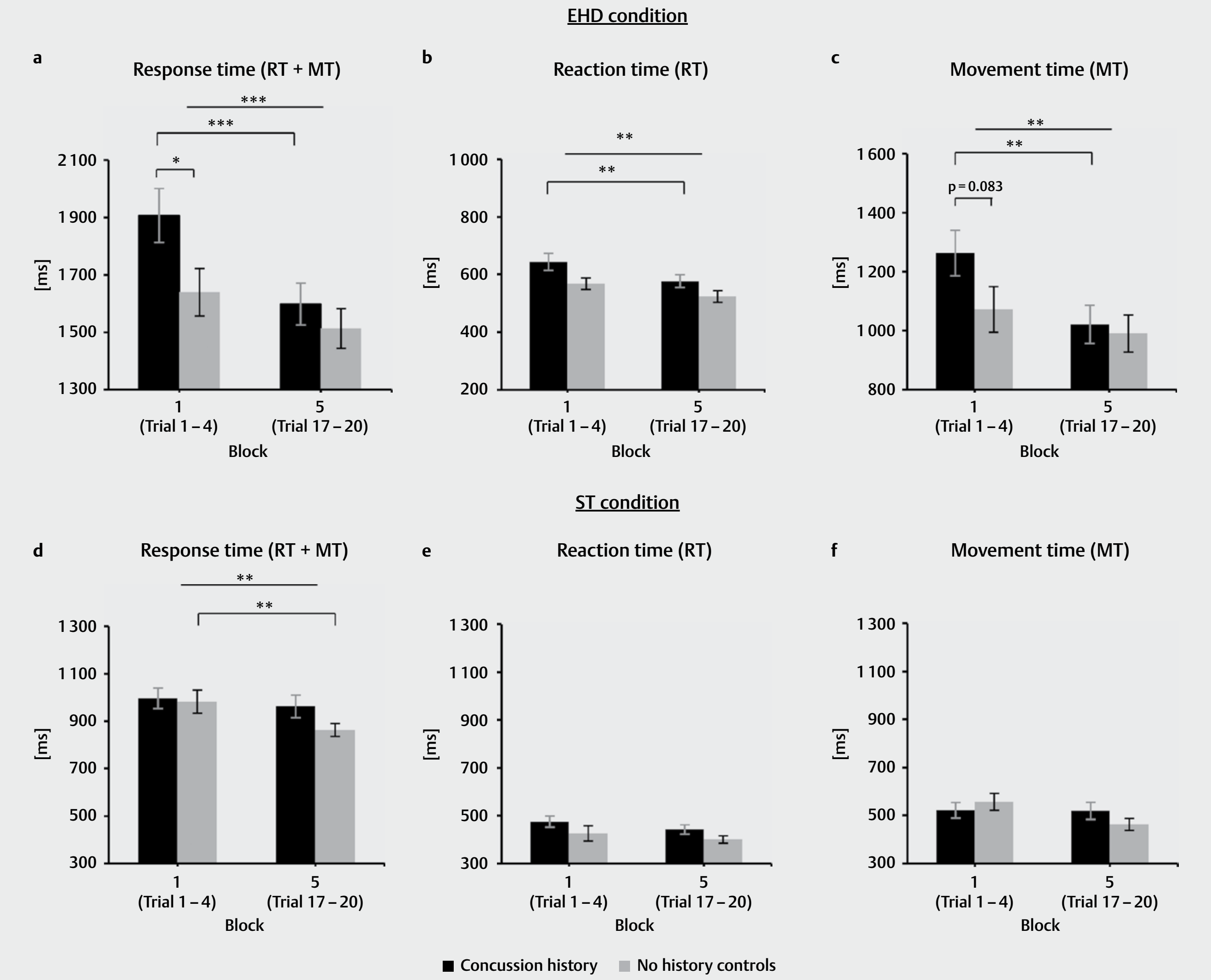
In summary, the current study expands previous work about youth with concussion history and their lingering prolonged behavioral performance deficits post-injury. The present results suggest that eye-hand decoupling deficits in youth with a concussion history were differently affected over a short series of visually guided reaching movements. The temporal aspects of performance preparation and execution were mainly deteriorated during the in-



▸ **Fig. 2** Mean response time (RespT), reaction time (RT), and movement time (MT) during the first, third, and last trial block in the EHD **a–c** and ST **d–f** task condition for youth with concussion history and no-history control participants. *=$p<0.05$, **=$p<0.01$, ***=$p<0.001$, n.s. = non significant. Error bars represent the standard error of the mean.

▸ **Table 3** Mean results for statistical outcomes of the repeated-measures mixed ANOVA of group (concussion history, no-history), block (1, 5), and condition (ST, EHD) for all dependent variables (RespT, RT, MT, PL). Abbreviations: ConcHist = Concussion History, No-Hist = No History; RespT = Response time, RT = Reaction time, MT = Movement time, PL = Path length; ST = Standard condition, EHD = Eye-hand decoupling; η^2 = partial eta square.

variable	**group**			**block**			**condition**			**group × block**		
	(ConcHist, No-Hist)			**(1, 5)**			**(ST, EHD)**					
	F (1,112)	**p - value**	**η^2**	**F (1,112)**	**p - value**	**η^2**	**F (1,112)**	**p - value**	**η^2**	**F (1,112)**	**p - value**	**η^2**
RespT	4.296	0.040	0.037	321.943	0.000	0.742	19.930	0.000	0.151	0.026	3.006	0.086
RT	5.104	0.026	0.044	91.038	0.000	0.448	7.946	0.006	0.066	0.226	0.635	0.002
MT	2.518	0.115	0.022	273.545	0.000	0.710	12.418	0.001	0.100	3.235	0.075	0.028
PL	4.529	0.036	0.039	26.441	0.000	0.191	0.076	0.783	0.001	2.689	0.104	0.023
variable	**group × condition**			**block × condition**			**group × block × condition**					
	F (1,112)	**p - value**	**η^2**	**F (1,112)**	**p - value**	**η^2**	**F (2,216)**	**p - value**	**η^2**			
RespT	1.181	0.279	0.010	5.856	0.017	0.050	5.647	0.019	0.048			
RT	0.213	0.645	0.002	1.431	0.234	0.013	0.242	0.624	0.002			
MT	0.962	0.329	0.009	3.955	0.049	0.034	4.905	0.029	0.042			
PL	0.064	0.800	0.001	0.021	0.885	0.000	0.272	0.603	0.002			
Significant and trend outcomes pair-wise comparisons:												
variable	**condition**			**block**								
RespT	EHD			1 (Trial 1-4)			F(1,118) = 4.691; p = 0.032					
MT	EHD			1 (Trial 1-4)			F(1,118) = 3.059; p = 0.083					



▶ **Fig. 3** Mean response time (RespT), reaction time (RT), and movement time (MT) during the first and last trial block in the EHD **a–c** and ST **d–f** task condition for youth with concussion history and no-history control participants. Note the performance difference (RespT, trend for MT) between the concussion history and no-history group in the first block of the EHD condition, an effect that diminished with task time and was completely absent in condition ST. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, n.s. = non significant. Error bars represent the standard error of the mean.

itial task period, supporting the notion that these youth with a concussion history have also difficulty to adapt to novel, challenging eye-hand decoupling tasks when vision and motor action are not aligned. The practical implication of our study is that probably athletes, coaches, and practitioners should be aware that youth players returning to game-play may need more time to prepare and execute movements, in particular, during the initial periods of spatially demanding eye-hand coordination tasks. Our findings may also partially explain why seemingly recovered youth with concussion history returning to game play have an elevated re-injury risk within the first twelve months post-event. Therefore, the current study may provide helpful information for coaches and movement practitioners working in professions and sports who encounter young contact sport players with high concussion rates.

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Responsibility for the contents of this study rests with the authors. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed. No writing assistance was utilized in the production of this manuscript.

Ethical Conduct of Research

The authors state that they have obtained appropriate institutional review board approval and have followed the principles outlined in the Declaration of Helsinki for all human or animal experimental investigations. In addition, for investigation involving human subjects, informed consent has been obtained from the participants involved.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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