Fact or Fiction, Accelerometry versus Self-Report in Adherence to Pediatric Concussion Protocols: A Prospective Longitudinal Cohort Study

Carol DeMatteo, Sarah Randall, Josephine Jakubowski, Kathy Stazyk, Joyce Obeid, Michael Noseworthy, Michael Mazurek, Brian W Timmons, John Connolly, Lucy Giglia, Geoffrey Hall, Chia-Yu Lin

Submitted to: JMIR Pediatrics and Parenting
on: February 12, 2024

Table of Contents

Fact or Fiction, Accelerometry versus Self-Report in Adherence to Pediatric Concussion Protocols: A Prospective Longitudinal Cohort Study

Carol DeMatteo[1, 2] MSc, DipP&OT; Sarah Randall[1, 2] MSc OT, OT Reg (Ont); Josephine Jakubowski[1] MSc; Kathy Stazyk[1] MSc; Joyce Obeid[3] PhD; Michael Noseworthy[4] PhD; Michael Mazurek[3] MD, FRCP(C); Brian W Timmons[3] PhD; John Connolly[5] PhD; Lucy Giglia[3] MD; Geoffrey Hall[5] PhD; Chia-Yu Lin[2] MSc

[1]Department of Rehabilitation Sciences McMaster University Hamilton CA
[2]CanChild Centre for Childhood Disability Research McMaster University Hamilton CA
[3]Department of Pediatrics McMaster University Hamilton CA
[4]School of BioMedical Engineering McMaster University Hamilton CA
[5]Department of Psychology and Behaviour McMaster University Hamilton CA

Corresponding Author:
Carol DeMatteo MSc, DipP&OT
Department of Rehabilitation Sciences
McMaster University
1400 Main Street West
Hamilton
CA

Abstract

Background: Concussion, or mild traumatic brain injury, is a growing public health concern, affecting approximately 1.2% of the population annually. Among children 1-17 years, concussion had the highest weighted prevalence compared to other injury types, highlighting the importance of addressing this issue among the youth population.

Objective: This study aimed to assess adherence to Return to Activity (RTA) protocols among youth with concussion and to determine if better adherence affected time to recovery and the rate of re-injury.

Methods: Children and youth (N=139) aged 5-18 with concussion were recruited. Self-reported symptoms and protocol stage of recovery were monitored every 48 hours until symptom resolution was achieved. Daily accelerometry was assessed with the ActiGraph®. Data was collected to evaluate adherence to the RTA protocol based on physical activity cut-off points corresponding to RTA stages. Participants were evaluated using a battery of physical, cognitive and behavioural measures, at recruitment, symptom-resolution and 3-months post symptom resolution.

Results: For RTA Stage 1, 13% of participants were adherent based on accelerometry, whereas 11% and 34% of participants were adherent for Stage 2 and 3, respectively. The median time to symptom resolution for participants who were subjectively reported adherent to the RTA protocol was 13 days and 20 days for those who subjectively were reported as (p=0.03). No significant agreement was found between self-report of adherence and objective actigraphy adherence to the RTA protocol, as well as to other clinical outcomes such as depression, quality of life and balance. The rate of re-injury among the entire cohort was 2% (N=3).

Conclusions: Overall, adherence to staged protocols post-concussion was minimal when assessed with accelerometers, but higher by self-report. More physical activity restrictions as specified in the RTA protocol, resulted in lower adherence. Although objective adherence was low, re-injury rate was lower than would be expected, suggesting a protective effect of being monitored and youth awareness of protocols. The results of this study support the move to less restrictive protocols and earlier resumption of daily activities that have since been implemented in more recent protocols. Clinical Trial: Canadian Institutes of Health Research (CIHR) grant number: 31257 to C.D.

(JMIR Preprints 12/02/2024:57325)
DOI: https://doi.org/10.2196/preprints.57325

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✔ **Please make my preprint PDF available to anyone at any time (recommended).**
Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✔ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**
Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

Original Manuscript

Original paper

Fact or Fiction, Accelerometry versus Self-Report in Adherence to Pediatric Concussion Protocols: A Prospective Longitudinal Cohort Study

Carol A DeMatteo[a,b,*], MSc, DipP&OT, Sarah Randall[a,b], MSc OT, OT Reg (Ont.), Josephine Jakubowski[a], MSc, Kathy Stazyk[a], MSc, Joyce Obeid[c], PhD, Michael Noseworthy[d], PhD, Michael Mazurek[c] MD, FRCP(C), Brian W. Timmons[c], PhD, John Connolly, PhD, Lucy Giglia[c], MD, Geoffrey Hall[e], PhD, Chia-Yu Lin[b], MSc.

Affiliations: [a]Department of Rehabilitation Sciences, McMaster University, Hamilton, Ontario, Canada, [b] CanChild Centre for Childhood Disability Research, McMaster University, Hamilton, Ontario, Canada, [c]Department of Pediatrics, McMaster Children's Hospital, Hamilton, Ontario, Canada, [d]School of BioMedical Engineering, McMaster University, Hamilton, Ontario, Canada, [e]Department of Psychology, Neuroscience and Behaviour, McMaster University, Hamilton, Ontario, Canada.

Corresponding Author: Carol A DeMatteo, School of Rehabilitation Science, Institute for Applied Health Sciences, McMaster University, 1400 Main Street West, Hamilton, ON, Canada, L8S 1C7, [dematteo@mcmaster.ca].

Abstract

Background: Concussion, or mild traumatic brain injury, is a growing public health concern, affecting approximately 1.2% of the population annually. Among children 1-17 years, concussion had the highest weighted prevalence compared to other injury types, highlighting the importance of addressing this issue among the youth population.

Objective: This study aimed to assess adherence to Return to Activity (RTA) protocols among youth with concussion and to determine if better adherence affected time to recovery and the rate of re-injury.

Methods: Children and youth (N=139) aged 5-18 with concussion were recruited. Self-reported symptoms and protocol stage of recovery were monitored every 48 hours until symptom resolution was achieved. Daily accelerometry was assessed with the ActiGraph®. Data was collected to evaluate adherence to the RTA protocol based on physical activity cut-off points corresponding to RTA stages. Participants were evaluated using a battery of physical, cognitive and behavioural measures, at recruitment, symptom-resolution and 3-months post symptom resolution.

Results: For RTA Stage 1, 13% of participants were adherent based on accelerometry, whereas 11% and 34% of participants were adherent for Stage 2 and 3, respectively. The median time to symptom resolution for participants who were subjectively reported adherent to the RTA protocol was 13 days and 20 days for those who subjectively were reported as nonadherent (p=0.03). No significant agreement was found between self-report of adherence and objective actigraphy adherence to the RTA protocol, as well as to other clinical outcomes such as depression, quality of life and balance. The rate of re-injury among the entire cohort was 2% (N=3).

Conclusions: Overall, adherence to staged protocols post-concussion was minimal when assessed with accelerometers, but higher by self-report. More physical activity restrictions as specified in the RTA protocol, resulted in lower adherence. Although objective adherence was low, re-injury rate was lower than would be expected, suggesting a protective effect of being monitored and youth awareness of protocols. The results of this study support the move to less restrictive protocols and earlier resumption of daily activities that have since been implemented in more recent protocols.

Trial Registration: Canadian Institutes of Health Research (CIHR) grant number: 31257 to C.D.

Keywords: Adherence, Guidelines, Pediatric Concussion, Return to School, Return to Sport

Introduction

Concussion, or mild traumatic brain injury, is a public health epidemic with an annual incidence of approximately 1.2% of the population [1]. According to the 2019 Canadian Health Survey on Children and Youth, head injuries or concussions had the highest weighted prevalence at 4.4% among children aged 1 to 17 years in Ontario, compared to other injury types. [2].

In 2015, our research team developed evidence-based Return to Activity (RTA) and Return to School (RTS) protocols for children and youth with concussion [3,4]. These protocols (now updated) [5], and similar protocols based on the Sports Concussion Consensus statements, [6,7], are the main management strategy for concussion recovery. It is important to determine if youth adhere to these protocols before they can be evaluated in randomized control trials. At present, the most common method to assess adherence to the RTA/RTS protocols in youth is through self-report [6,8]. Literature suggests, however, that self-reported adherence estimates in youth are impacted by time since injury, age, mechanism of injury, receptivity to recommendations and gender differences in activity [9-11]. To assess adherence, device-based measures of physical activity should be employed as they are reliable and minimize the bias associated with self-report [12-18]. As such, the primary aim of this study was to evaluate adherence to the RTA protocol using accelerometry and compare accelerometry-based adherence to self-report. The secondary objective was to evaluate post-concussion symptoms, recovery times and rate of repeat head injury, as well as to determine an association between adherence to RTA protocols and outcomes related to symptoms, repeat head injury, cognition, balance, quality of life (QoL) and depression. It was hypothesized that youth who were more adherent would have a lower incidence of repeat injury, shorter times to RTA and better outcomes in QoL, mental health, and cognition. Henceforth, youth will be used to refer to the 5-18 year old participants in this study.

Methods

Study Design

This study was approved by the local Research Ethics Board. Participants were recruited from the local Hospital Emergency Department, community referrals from their primary physician, and rehabilitation or sports medicine clinics. Eligibility criteria included: a diagnosis of concussion by a physician within 12 months, 5-18 years of age, active symptomatology and English speaking. Youth were deemed ineligible if they had a confirmed brain injury requiring resuscitation, admission to the pediatric critical care unit, surgical intervention, or refused to wear the ActiGraph. Informed assent/consent were obtained from participants and parents. This prospective longitudinal cohort study had three measurement time points: recruitment/first visit, symptom-resolution, and final visit, which occurred 3 months post-symptom-resolution or 6 months post-enrolment if symptoms did not resolve within the time frame of study. This investigation consisted of various outcomes including EEG, [19,20] MRI, [21] cognition [22,23] and sleep [24] which were published previously. Data on self-reported adherence and adherence to RTS protocols specifically, was published by DeMatteo et al, 2021[25].

Assessment of RTA and RTS Protocol Stage and Symptoms

The CanChild protocols [3,4] consist of 6 stages of RTA and 5 stages of RTS, made with refrence to the Zurich guidelines [26]. Youth were advised that no high intensity physical activity or contact sport was permitted while they were symptomatic. They were also informed that “rest” does

not equate to social isolation or sensory deprivation. Once recruited, youth received the ActiGraph and the 2015 CanChild protocols [3,4] immediately. Participants completed surveys every 48-hours using REDCap, Research Electronic Data Capture (a browser-based data management application) [27]. The surveys included the Post-Concussion Symptom Scale (PCSS), [28] RTA/RTS stages as well as an assessment of cognitive activity [3]. The PCSS [28] is common across concussion evaluations [7] and consists of a 22-symptom checklist scored on a 0-6 Likert scale. This was adapted for younger children using a dichotomous scale of yes/no [29]. The cognitive scale assessed cognitive activity on a scale of 1-5 and was adapted from Brown et al. [30]. The second in-person visit occurred at symptom-resolution. The label of symptomatic or non-symptomatic was based on the return of participants' self-identified current reporting of symptoms to their pre-injury symptom status.

Measurement of Adherence to Protocols

To assess physical activity in the RTA protocols, youths were outfitted with an ActiGraph Gt3X waist-worn monitor accelerometer (ActiGraph LLc, Pensacola, FL). The ActiGraph accelerometer provides a high-resolution measure of the duration, intensity and frequency of movement, and is validated for use in youth [12-17]. Participants were provided standardized instructions on how to wear the accelerometer and to record times of non-wear in a log diary. Accelerometry data were downloaded into 30-second epochs and visually inspected, by trained personnel, to ensure wear times matched those reported by participants. The data was cleaned to remove any non-wear periods or spurious data using V6.13.4 ActiLife/ActiGraph LLc, Pensacola, FL. The 30-second epoch was selected for analyses as shorter epochs are more accurate to measure exercise intensity during intermittent physical activity [31]. Only valid days, defined as at least 6 hours and no more than 19 hours of wear-time, were included in analysis. Activity count data were then scored for analysis of adherence. To do this, daily time spent being sedentary, light (LPA), moderate, vigorous (VPA), and moderate-to-vigorous physical activity (MVPA) were calculated using the Evenson et al [14] cut-points. Youth were considered adherent if there was 80% adherence to the physical activity requirements for the corresponding stage of RTA protocol. Only participants who had complete actigraphy data were included in analyses (n =84). For Stage 1, unlimited LPA was permitted, MVPA was limited to ≤2.5% of wear time and no consecutive bouts of ≥5-minutes at any intensity were recommended. In Stage 2, baseline activity observed in Stage 1 was permitted, as well as an extra 30 minutes of LPA, but no consecutive bouts of ≥5-minute of MVPA were recommended. In Stage 3, baseline activity observed in Stage 2 was permitted, as well as an extra 60 minutes of MVPA and ≤ 2, two 15-minute bouts of MVPA. Only adherence to RTA Stages 1-3 were assessed with accelerometry because these stages had quantifiable activity amounts defined in the RTA protocol [4], and RTS did not have objective adherence data.

Subjective reported adherence to the RTA/RTS protocols was based on the following criteria: if participants received a label of “yes” to the questions answered by research personnel: Has the child been following the RTA/RTS guidelines correctly, based on a self-reported progression through the RTA/RTS stages being associated with a decreasing self-report PCSS score [8]. Participants were categorized separately for each of RTA and RTS. Participants labelled as “Did Not Adhere” to both RTS and RTA, as well as participants labelled as “Adhered” to one, but not both RTA and RTS protocols, were deemed “Did Not Adhere”.

Standardized Neurocognitive, Depression and Quality of Life, Coordination and Balance Tests

Participants completed the Children’s Depression Inventory short form (CDI) [32], the KIDSCREEN-52 [33], Immediate Post Concussion & Cognitive Test (ImPACT) [34] and subsets of balance, bilateral coordination, running speed and agility and strength in Bruininks-Oseretsky Test of

Motor Proficiency 2nd edition (BOT-2) [35] at each in-person visit.

Statistical Analyses

Demographic, injury data are presented as mean±standard deviation (SD), recruitment details are reported in percentages (%), and PCSS score is reported as the median as more reflective of the data due to a few outliers. Per participant adherence was calculated for Stages 1-3 of RTA as described above. Adherence was apriori determined to be considered the primary predictor of outcomes, but as the adherence rate was very low, alternative analyses were performed (see results). The ActiGraph calculated adherence for RTA was then compared to the self-reported rating of adherence for RTA and agreement was assessed using Cohen's κ (kappa).

The rate of repeat head injury was calculated as a percentage of total injuries. A Mann-Whitney-U Test was performed to assess time to RTA Stage 3 and 6 and time to symptom resolution for those who adhered or did not adhere [15, 36]. Only participants who reported continued symptoms up until 3 months post symptom resolution, self-reported adherence to RTA/RTS and reported the final stage of RTA/RTS, were analyzed. Participants who responded "no" to the question "On more than one occasion, have you had any symptoms of concussion in the last two weeks?" were given a PCSS score of 0. Significance was set at p=0.05. Scores for the BOT-2, CDI, ImPACT and KIDSCREEN-52 are reported as mean±SD and median. All the data was tested for normality using the Shapiro-Wilk test. Time to symptom resolution, time to stage, and PCSS scores were not normally distributed. Data was analyzed using SAS version 9.4 and SPSS Statistical version 23.0, with significance set at $p<0.05$.

Results

Of the 139 participants who consented to the study, 107 participants (77%) completed follow-up assessments, 12 participants (9%) were lost to follow-up, and 20 participants (14%) withdrew from the study. Of the 20 participants who withdrew, 7 participants (35%) did so immediately after consent, 12 participants (60%) withdrew after the first in-person visit and 1 participant (5%) withdrew before the final visit.

The cohort included 64 boys (46%) and 75 girls (54%) with a median age of 13.4 years. Seventy-four percent of participants (n=103) sustained their concussion via a sports-related injury, with most injuries obtained during recreational play (n=29, 28%) and ice hockey (n=26, 25%). This was the first concussion for 58% of participants (Table 1). The median time from injury to the first visit was 7.8 days (Mean: 34.8 days, Minimum: 2.9 hours and Maximum: 320.9 days). Time from injury to the Symptom Resolution In Person Visit and Final visit is 95.4±43.4 days and 162.6±75.7 days, respectively.

Table 1. Participant Demographics, Symptom Resolution and Rate of Re-Injury (N=139)

Recruitment (N=139)	
Age	
Mean ± SD	13 ± 2.85
Median (Q1, Q3)	13.4 (10.9, 15.2)
Male, N (%)	64 (46%)
Number of Previous Concussions, N (%)	
0	81 (58%)
1-2	45 (32%)
3-5	8 (6%)
6+	4 (3%)
Mechanism of Injury, N (%)	

Sports/Recreational Play	103 (74%)
Non-sport related injury/fall	22 (16%)
Assault	5 (4%)
Motor Vehicle Collision	4 (3%)
Other	3 (2%)
Post-Concussion Symptom Scale (PCSS) Baseline score, N=131	
Median (Q1, Q3)	36 (17, 56)
Achieved Symptom Resolution, N=114	
Symptom free within 7 days	2 (2%)
Symptom free 8- 14 days	16 (14%)
Symptom free 15-28 days	31 (27%)
Symptom free 29-89 days	35 (31%)
Symptom free > 90 days	14 (12%)
Never achieved symptom resolution	16 (14%)
Withdrew/Lost to follow-up prior to Symptom resolution, N=25	
Unknown	11 (44%)
Past 30 days	3 (12%)
Past 60 days	2 (8%)
Past 90 days	9 (36%)
Rate of Re-Injury	
Re-injury, N (%)	3 (2.1%)

Of participants who remained in active enrollment (n=114), 16 participants (14%) did not achieve symptom-resolution in the 6-month follow-up period (Table 1). Median time to symptom resolution was 16 days (Mean 27±33 days).

The rate of participants having another concussion during the follow up period was 2% (N=3).

ActiGraph Adherence Evaluation

Per *participant analysis* indicated that 13% of participants adhered to Stage 1, 11% adhered to Stage 2 and 34% adhered to Stage 3. Of note, only one participant from this cohort (N=139) adhered to all three stages.

Table 2. Overall Days of ActiGraph Adherence to the Return to Activity Protocols among Participants (N=97)

Daily Adherence			
RTA Stage	Total Days N	Days of Adherence	Days of No Adherence
1	68	6 (9%)	62 (91%)
2	403	28 (7%)	375 (93%)
3	218	48 (22%)	170 (78%)
Stage 1-3	689	82 (12%)	607 (88%)

ActiGraph data with sufficient wear time and corresponding PCSS score and RTA stage was considered complete and then analyzed in 30-second epochs for 80% adherence to Stage 1, 2 and 3. Participants were labelled as “Adhered” to each stage if they had at least 1 day in adherence to ActiGraph cut points for Stage 1, Stage 2 or Stage 3. Participants were given a final label of “Did Not Adhere” if they did not meet the cut points corresponding to Stage 1, 2 or 3.

Subjective Reported Adherence

Of the 105 participants for which there were self-reported data, 59 participants (56%) adhered to the RTA protocol [11], 56 participants (53%) adhered to the RTS protocol and 51% were adherent to both protocols. (Table 3).

Table 3. Subjective Adherence reported for the Return to School and Return to Activity Protocols (N=105)

	Return to School (RTS)	Return to Activity (RTA)	RTS and RTA
N (%)			
Adhered	56 (53%)	59 (56%)	53 (51%)
Did Not Adhere	49 (47%)	46 (44%)	52 (49%)
Total	105	105	105

Objective ActiGraph versus Subjective Self-Report

Cohen's κ was performed to determine if there was agreement in Actigraphy and self-report of adherence to the RTA protocol. There was no statistically significant agreement between the two measures k=0.49 (95%CI: 0.32-0.66) p=0.57 (Table 4). Of the 84 participants with both ActiGraph and self-report data, there was 48% agreement between the two (n=40). Forty three percent of these participants (n=36) self-reported adherence to the RTA protocol but failed to meet the ActiGraph adherence cut points.

Table 4. Agreement of Adherence between ActiGraph vs. Subjective Report (N=84)

	Actigraphy		
Subjective Report	Adhered	Did Not Adhere	Total
Adhered	16	36	52
Did Not Adhere	8	24	32
Total	24	60	84
Kappa	k=0.49 (95%CI: 0.32 to 0.66)		p = 0.57

Time to Symptom Resolution and RTA/RTS Completion

Those with subjective reported adherence to the RTA protocol had a significantly shorter time in days to symptom resolution (Median=13) than those who did not subjectively adhere (Median=20), U=724.50, *p*=0.03. (Table 5).

Table 5. Time to Symptom Resolution and PCSS score for Youth with Concussion based on Subjective Adherence or Nonadherence to the RTA and RTS Protocols (N=90)

Return to Activity			Return to School		
Adhered	Did Not Adhere	Sig.	Adhered	Did Not Adhere	Sig.

N	49	41		47	43	
Days, Mean ± SD	23.0 ± 30.7	32.9 ± 36.6		21.6 ± 26.1	34.0 ± 39.7	
Median	13.0	20.0		13.0	17.0	
Min	2.0	2.0		2.0	2.0	
Max	157.0	174.0		157.0	174.0	
Mean Rank	40.15	51.89	0.03*	41.38	50.0	0.12
PCSS score at Symptom Resolution						
	Adhered	Did Not Adhere	Sig.	Adhered	Did Not Adhere	Sig.
N	40	37		44	42	
Mean ± SD	2.4 ± 10.6	7.4 ± 15.1		4.5 ± 11.7	7.4 ± 14.6	
Median	0.0	0.0		0.0	0.0	
Mean Rank	37.06	41.09	0.29	42.90	44.13	0.78

The difference in time to Symptom Resolution was assessed, using a Mann-Whitney U test, for participants who self-report adherence and non-adherence to RTA and RTS (N=90). Time to symptom resolution was calculated as the time from initial injury to symptom resolution. Only participants who had a date of symptom resolution verified by Research Personnel were included in the analyses.

There was no statistically significant difference in the time from injury to RTA Stage 3 (p=0.61) or Stage 6 (p=0.24) for participants who self-reported adherence or nonadherence (Table 6).

Table 6. Time in Days to Return to Activity and Return to School for Youth with Concussion based on Subjective Adherence or Nonadherence to the RTA Protocol (N=105)

	Return to Activity Stage 3			Return to Activity Stage 6		
	Adhered	Did Not Adhere	p	Adhered	Did Not Adhere	p
N	34	19		41	36	
Days, Mean ± SD	56.4 ± 60.1	38.8 ± 54.9	0.61	59.9 ± 41.5	63.1 ± 65.3	0.24
Days, Median	29.8	15.2		47.3	31.6	
Days, Min	7	6		12	11	
Days, Max	247	221		156	276	
	Return to School Stage 3			Return to School Stage 5		
	Adhered	Did Not Adhere	p	Adhered	Did Not Adhere	p
N	36	22		47	41	
Days, Mean ± SD	28.3 ± 39.9	13.2 ± 8.7	0.06	65.2 ± 57.9	58.9 ± 64.2	0.05
Days, Median	13.8	10.7		45.7	27.5	
Days, Min	5	5		11	7	
Days, Max	199	44		252	253	

PCSS score at Symptom Resolution

The difference in average number of symptoms as reported on the PCSS/PCSI at Stage 5 of RTS and Stage 6 of RTA was assessed, using a Mann-Whitney U test, for participants who self-report adherence and non-adherence to RTS/RTA protocols (N=86). There was no statistically significant difference in PCSS score at Stage 5 or Stage 6 of RTS (p=0.78) and RTA (p=0.29), respectively, for participants who adhered or did not adhere to the protocols (Table 5).

Adherence and Non-Adherence: Depression and Quality of Life, Neurocognitive and Balance tests

The KIDSCREEN-52 Physical and Psychological Well-being subsections scores improved from the first to final visit across most participants. The scores were considered “high” demonstrating that participants felt they were physically fit, healthy and viewed life positively [30]. Participants’ CDI total T- score decreased for symptoms of depression from the first to final visit (p>0.05) where scores were in the average/low range (<60). Across all three visits, most participants scored in the “average” category. From the first to final visit, ImPACT subsection scores increased suggesting an improvement in cognitive performance (p>0.05).

There was no significant difference in the BOT-2, CDI, KIDSCREEN-52 total or subsection scores between those who reported they subjectively adhered or did not adhere to the RTA and RTS protocols. There was a significant difference in the ImPACT Impulse Control Composite Score at the final visit for those who adhered to the RTA protocol (7.3±5.1) vs. those who did not adhere (11.9±11.7, p=0.04).

Discussion

This prospective cohort study examined adherence to the RTA protocol, the rate of re-injury and time to symptom resolution among youths with concussion. It is one of few investigations which has assessed physical activity in youths with concussion using the accelerometry [37]. Our findings indicate that youths have lower adherence, as measured by accelerometry, to RTA stages when there is greater physical activity restriction and adherence improves as more activity is allowed. Actigraphy analysis showed that 13% of participants were adherent to RTA Stage 1, 11% were adherent to Stage 2 and 34% of participants were adherent to Stage 3. Huber et al [38] examined collegiate and high school football players post-concussion with the Fitbit Charge HR. The authors found that athletes with concussion had a great deal of variability in activity levels the first few days post-injury suggesting differences in how the athletes interpreted “rest”. Although in Huber et al [38] the activity monitors were worn for only two weeks, their findings are similar to ours in that there is lower adherence in the early stages. In our study, the generally low adherence rate was not conducive to any statistical prediction analyses or modelling as the study had set, as an apriori standard, that 80% compliance must be achieved to qualify as “adherent” and then to predict if these adherent youth had better outcomes. This required examining the data in other ways, resulting in compelling findings. First, we observed that the PCSS score decreased as youth progressed through the RTS/RTA protocols [25] and were low at the final stage of RTS/RTA despite low adherence according to activity monitoring. We also observed a rate of re-injury of merely 2% which is lower than rates presented in literature [39, 40]. In addition, the same referral-based sample of patients at the McMaster Acquired Brain Injury Concussion Clinic in 2013-2014, (before the RTA/RTS protocols were first introduced) documented a re-injury rate of 37% of the 464 youths followed clinically. Notably, 36 participants (43%) self-reported adherence to the RTA protocol but failed to meet the actigraphy cut points. This suggests they believed that they were following the activity recommendations outlined in the protocols. It is speculated that they had modified their typical activities to some degree which then felt like adherence to them. Presumably, their activity choices were guided by symptom relief and moderated by the conservative approach used in the CanChild

protocols [3,4]. It also suggests that our arbitrary choice of 80% for a label of adherence was unrealistic, too high and maybe even unnecessary. It was observed that participants who self-reported adherence to the RTA protocols achieved symptom resolution in a median of 13 days and those who self-reported non-adherence achieved symptom resolution in 20 days. This data suggests that the mere presence of the protocols may alter behaviours which facilitates symptom resolution and reduces rates of re-injury as noted above.

The lack of adherence meant the youth were doing more than recommended by the protocols and may seem in contrast to the low re-injury rate and symptom recovery patterns, but existing evidence has shown that some cognitive and physical exertion early in recovery leads to shorter recovery times and improvement in symptoms [32, 33, 39-43]. In addition, Grool et al [44] examined 2,413 youths with concussion and observed that physical activity within 7 days of acute injury was associated with reduced risk of persistent post-concussion symptoms [44]. So, the non-adhering youth in our study were, in fact, getting some physical and cognitive activity early on. Yet the fact that they were not fully participating in activity may have contributed to the positive outcomes. The patterns demonstrated by the youth in this study provide valuable information for clinicians. They help define what activities and treatments are tolerable and acceptable for youth post-concussion, meaning these are the levels of activity and treatment that youths can manage without exacerbating symptoms or causing further harm. Additionally, the study may indicate what is helpful, meaning the interventions or practices that contribute to positive outcomes and aid in the recovery process.

In light of these findings [25], and data from our systematic review [45], the RTA/RTS protocols have been updated [5]. Some major revisions include a shortened rest period in Stage 1 and the recommendation that youth progress through the stages before they are symptom-free [5]. With these latest revisions, adherence of youth to the 2019 RTA/RTS protocols is expected to be greatly improved, although this requires further investigation.

This investigation is not without limitations. First, data on race and socioeconomic status was not collected. Second, adherence to RTA Stages 1-3, but not Stages 4-6, were assessed because only these stages had quantifiable physical activity cut-points. With this, we were unable to objectively assess adherence to the later stages of the RTA protocol. Third, we accepted youth with concussion experiencing both acute and prolonged symptoms due to the nature of the research question. As such, the variability in time to symptom resolution and stage may be due to the prolonged symptoms of some participants. Finally, although we were able to retain the majority of participants, some were lost to follow-up or never achieved symptom resolution within the study period.

Overall, adherence to staged protocols post-concussion was minimal according to the accelerometric data, but higher by self-report. More physical activity restrictions as specified in the RTA protocol, resulted in lower adherence. Although adherence was low, re-injury rate was lower than would be expected, suggesting a protective effect of being monitored and youth awareness of protocols. The results of this study support the move to less restrictive protocols and earlier resumption of daily activities that have since been implemented in more recent protocols.

Acknowledgements

The authors would like to thank the participating families in this study for their effort and commitment, and all the Back to Play team members for their hard work and support throughout all stages of this project. We would also like to thank CHIR for funding as well as the local Children's Hospital Emergency Department staff and physicians for recruitment support.

Conflict of Interest

None declared.

Abbreviations

BOT-2: Bruininks-Oseretsky Test of Motor Proficiency 2nd edition
CDI: Children's Depression Inventory
ImPACT: Immediate Post Concussion & Cognitive Test
LPA: Light physical activity
MVPA: moderate-to-vigorous physical activity
PCSS: Post-Concussion Symptom Scale
QoL: Quality of life
RTA: Return to Activity
RTS: Return to School
VPA: Vigorous physical activity

References

1. Langer L, Levy C, Bayley M. Increasing Incidence of Concussion: True Epidemic or Better Recognition?. *J Head Trauma Rehabil*. 2020;35(1):E60-E66. doi:10.1097/HTR.0000000000000503
2. Ontario Agency for Health Protection and Promotion (Public Health Ontario). Injuries among children using the Canadian Health Survey on Children and Youth. 2nd ed. Toronto, ON: King's Printer for Ontario; 2024. ISBN: 978-1-4868-7962-5
3. DeMatteo C, Stazyk K, Giglia L, et al. A Balanced Protocol for Return to School for Children and Youth Following Concussive Injury. Clin Pediatr (Phila). 2015;54(8):783-792. doi:10.1177/0009922814567305
4. DeMatteo C, Stazyk K, Singh SK, et al. Development of a conservative protocol to return children and youth to activity following concussive injury. *Clin Pediatr (Phila)*. 2015;54(2):152-163. doi:10.1177/0009922814558256
5. DeMatteo C, Randall S, Falla K, et al. Concussion Management for Children Has Changed: New Pediatric Protocols Using the Latest Evidence. *Clin Pediatr (Phila)*. 2020;59(1):5-20. doi:10.1177/0009922819879457
6. McCrory P, Meeuwisse W, Dvořák J, et al. Consensus statement on concussion in sport-the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med*. 2017;51(11):838-847. doi:10.1136/bjsports-2017-097699
7. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med*. 2013;47(5):250-258. doi:10.1136/bjsports-2013-092313
8. DeMatteo CA, Lin CA, Foster G, et al. Evaluating Adherence to Return to School and Activity Protocols in Children After Concussion. *Clin J Sport Med*. 2021;31(6):e406-e413. doi:10.1097/JSM.0000000000000800
9. Gagnon I, Swaine B, Forget R. Using activity diaries to measure children's and adolescents' compliance with activity restrictions after mild traumatic brain injury. *J Head Trauma Rehabil*. 2009;24(5):355-362. doi:10.1097/HTR.0b013e3181b97a4e
10. Jago R, Anderson CB, Baranowski T, Watson K. Adolescent patterns of physical activity differences by gender, day, and time of day. *Am J Prev Med*. 2005;28(5):447-452. doi:10.1016/j.amepre.2005.02.007
11. Moor HM, Eisenhauer RC, Killian KD, et al. The relationship between adherence behaviors and recovery time in adolescents after a sports-related concussion: an observational study. *Int J Sports Phys Ther*. 2015;10(2):225-233
12. Cain KL, Sallis JF, Conway TL, Van Dyck D, Calhoon L. Using accelerometers in youth physical activity studies: a review of methods. *J Phys Act Health*. 2013;10(3):437-450. doi:10.1123/jpah.10.3.437
13. Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S. Assessment of physical activity in youth. *J Appl Physiol (1985)*. 2008;105(3):977-987. doi:10.1152/japplphysiol.00094.2008
14. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci*. 2008;26(14):1557-1565. doi:10.1080/02640410802334196
15. Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. *Med Sci Sports Exerc*. 2005;37(11 Suppl):S523-S530. doi:10.1249/01.mss.0000185658.28284.ba

16. Reilly JJ, Penpraze V, Hislop J, Davies G, Grant S, Paton JY. Objective measurement of physical activity and sedentary behaviour: review with new data. *Arch Dis Child*. 2008;93(7):614-619. doi:10.1136/adc.2007.133272
17. Rowlands AV. Accelerometer assessment of physical activity in children: an update. *Pediatr Exerc Sci*. 2007;19(3):252-266. doi:10.1123/pes.19.3.252
18. Sirard JR, Pate RR. Physical activity assessment in children and adolescents. *Sports Med*. 2001;31(6):439-454. doi:10.2165/00007256-200131060-00004
19. Boshra R, Ruiter KI, DeMatteo C, Reilly JP, Connolly JF. Neurophysiological Correlates of Concussion: Deep Learning for Clinical Assessment. *Sci Rep*. 2019;9(1):17341. Published 2019 Nov 22. doi:10.1038/s41598-019-53751-9
20. Ruiter KI, Boshra R, DeMatteo C, Noseworthy M, Connolly JF. Neurophysiological markers of cognitive deficits and recovery in concussed adolescents. *Brain Res*. 2020;1746:146998. doi:10.1016/j.brainres.2020.146998
21. Dona O, Noseworthy MD, DeMatteo C, Connolly JF. Fractal analysis of brain blood oxygenation level dependent (BOLD) signals from children with mild traumatic brain injury (mTBI). PLoS One. 2017;12(1):e0169647. doi:10.1371/journal.pone.0169647. PMID: 28072842; PMCID: PMC5224975
22. Ho RA, Hall GB, Noseworthy MD, DeMatteo C. An Emotional Go/No-Go fMRI study in adolescents with depressive symptoms following concussion. *Int J Psychophysiol*. 2018;132(Pt A):62-73. doi:10.1016/j.ijpsycho.2017.09.021
23. Ho RA, Hall GB, Noseworthy MD, DeMatteo C. Post-concussive depression: evaluating depressive symptoms following concussion in adolescents and its effects on executive function. *Brain Inj*. 2020;34(4):520-527. doi:10.1080/02699052.2020.1725841
24. Berger I, Obeid J, Timmons BW, DeMatteo C. Exploring Accelerometer Versus Self-Report Sleep Assessment in Youth With Concussion. *Glob Pediatr Health*. 2017;4:2333794X17745973. Published 2017 Dec 7. doi:10.1177/2333794X17745973
25. DeMatteo CA, Lin CA, Foster G, et al. Evaluating Adherence to Return to School and Activity Protocols in Children After Concussion. *Clin J Sport Med*. 2021;31(6):e406-e413. doi:10.1097/JSM.0000000000000800
26. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *J Athl Train*. 2009;44(4):434-448. doi:10.4085/1062-6050-44.4.434
27. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42(2):377-381. doi:10.1016/j.jbi.2008.08.010
28. Lovell MR, Collins MW. Neuropsychological assessment of the college football player. *J Head Trauma Rehabil*. 1998;13(2):9-26. doi:10.1097/00001199-199804000-00004
29. Sady MD, Vaughan CG, Gioia GA. Psychometric characteristics of the postconcussion symptom inventory in children and adolescents. *Arch Clin Neuropsychol*. 2014;29(4):348-363. doi:10.1093/arclin/acu014
30. Brown NJ, Mannix RC, O'Brien MJ, Gostine D, Collins MW, Meehan WP 3rd. Effect of cognitive activity level on duration of post-concussion symptoms. *Pediatrics*. 2014;133(2):e299-e304. doi:10.1542/peds.2013-2125
31. Fabre N, Lhuisset L, Bernal C, Bois J. Effect of epoch length on intensity classification and on accuracy of measurement under controlled conditions on treadmill: Towards a

better understanding of accelerometer measurement. *PLoS One*. 2020;15(1):e0227740. Published 2020 Jan 24. doi:10.1371/journal.pone.0227740
32. Kovacs, M., & MHS Staff. (2003). The Children's Depression Inventory (CDI). Technical manual update. Toronto, Canada: Multi-Health Systems. [PDF].
33. Ravens-Sieberer U, Gosch A, Rajmil L, et al. The KIDSCREEN-52 quality of life measure for children and adolescents: psychometric results from a cross-cultural survey in 13 European countries. *Value Health*. 2008;11(4):645-658. doi:10.1111/j.1524-4733.2007.00291.x
34. ImPACT Concussion Test | ImPACT Applications. Published July 12, 2017. Available from: https://impactconcussion.com/. Accessed July 12, 2017.
35. Bruininks R, Bruininks B. Bruininks-Oseretsky Test of Motor Proficiency, Second Edition. Minneapolis, MN: NCS Pearson; 2005. Available from: https://www.pearsonassessments.com/store/usassessments/en/Store/Professional-Assessments/Motor-Sensory/Bruininks-Oseretsky-Test-of-Motor-Proficiency-%7C-Second-Edition/p/100000648.html. Accessed July 16, 2023.
36. DeMatteo CA, Randall S, Lin CA, Claridge EA. What Comes First: Return to School or Return to Activity for Youth After Concussion? Maybe We Don't Have to Choose. *Front Neurol*. 2019;10:792. Published 2019 Jul 23. doi:10.3389/fneur.2019.00792
37. Ledoux AA, Barrowman NJ, Boutis K, et al. Multicentre, randomised clinical trial of paediatric concussion assessment of rest and exertion (PedCARE): a study to determine when to resume physical activities following concussion in children. Br J Sports Med. 2019;53(3):195. doi:10.1136/bjsports-2017-097981. PMID: 28701360.
38. Huber DL, Thomas DG, Danduran M, Meier TB, McCrea MA, Nelson LD. Quantifying Activity Levels After Sport-Related Concussion Using Actigraph and Mobile (mHealth) Technologies. *J Athl Train*. 2019;54(9):929-938. doi:10.4085/1062-6050-93-18
39. Greco T, Ferguson L, Giza C, Prins ML. Mechanisms underlying vulnerabilities after repeat mild traumatic brain injuries. *Exp Neurol*. 2019;317:206-213. doi:10.1016/j.expneurol.2019.01.012
40. Swaine BR, Tremblay C, Platt RW, Grimard G, Zhang X, Pless IB. Previous head injury is a risk factor for subsequent head injury in children: a longitudinal cohort study. *Pediatrics*. 2007;119(4):749-758. doi:10.1542/peds.2006-1186
41. Leddy JJ, Haider MN, Ellis M, Willer BS. Exercise is Medicine for Concussion. *Curr Sports Med Rep*. 2018;17(8):262-270. doi:10.1249/JSR.0000000000000505
42. Leddy JJ, Haider MN, Hinds AL, Darling S, Willer BS. A Preliminary Study of the Effect of Early Aerobic Exercise Treatment for Sport-Related Concussion in Males. *Clin J Sport Med*. 2019;29(5):353-360. doi:10.1097/JSM.0000000000000663
43. Sawyer Q, Vesci B, McLeod TC. Physical Activity and Intermittent Postconcussion Symptoms After a Period of Symptom-Limited Physical and Cognitive Rest. *J Athl Train*. 2016;51(9):739-742. doi:10.4085/1062-6050-51.12.01
44. Grool AM, Aglipay M, Momoli F, et al. Association Between Early Participation in Physical Activity Following Acute Concussion and Persistent Postconcussive Symptoms in Children and Adolescents. *JAMA*. 2016;316(23):2504-2514. doi:10.1001/jama.2016.17396
45. DeMatteo C, Bednar ED, Randall S, Falla K. Effectiveness of return to activity and return to school protocols for children postconcussion: a systematic review. *BMJ Open Sport Exerc Med*. 2020;6(1):e000667. Published 2020 Feb 24. doi:10.1136/bmjsem-2019-

000667

Supplementary Files

Related publication(s) - for reviewers eyes onlies

Author Contributions.
URL: http://asset.jmir.pub/assets/9a6211320d947ea7271c0a15b5b3491a.pdf