

## Virtual reality in concussion management: from lab to clinic

Fernando V. Santos, Felipe Yamaguchi, Thomas A. Buckley, Jaclyn B. Caccese

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### Handling editor:

Nicholas G Murray, Ph.D.  
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Neuromechanics Laboratory UNITED STATES*

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### 1<sup>st</sup> Editorial decision

7-Feb-2020

Ref.: Ms. No. JCTRes-D-19-00038  
Virtual Reality in Concussion Management: From Lab to Clinic  
Journal of Clinical and Translational Research

Dear Dr Caccese,

Reviewers have now commented on your paper. You will see that they are advising that you revise your manuscript. If you are prepared to undertake the work required, I would be pleased to reconsider my decision.

For your guidance, reviewers' comments are appended below.

If you decide to revise the work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript. Also, please ensure that the track changes function is switched on when implementing the revisions. This enables the reviewers to rapidly verify all changes made.

Your revision is due by Mar 08, 2020.

To submit a revision, go to <https://www.editorialmanager.com/jctres/> and log in as an Author.

You will see a menu item call Submission Needing Revision. You will find your submission record there.

Yours sincerely

Nicholas G Murray, Ph.D.  
Editorial Board Member  
Journal of Clinical and Translational Research

Reviewers' comments:

Reviewer #1: General Comments:

Overall, this article is well written with some interesting information that is somewhat relevant to the field of study. One major concern is that the authors are differentiating between what is augmented versus virtual reality. Many assessments noted by the authors are using augmented reality (see specific comments) and these are typically game-like interfaces (i.e. any wii gaming based assessments) as compared to fully immersive environments that block out all external stimuli.

The second major concern for this article is the lack of a methods section. It is completely understandable to have a non-systematic literature review, however, some aspect of a methods section should be included in the article. For example, which search engines were used, how articles were selected (inclusion/exclusion criteria), and search terms is required. Please add this important section to the manuscript.

Third less severe concern is that the discussion should include how this information is relevant to clinicians. This article contains a high amount of jargon and some of that is not translatable to athletic trainers or other clinicians. Please tone down or define the jargon across the entire manuscript while simultaneously adding in or clarifying in the discussion what tools/items/other are currently available for use for clinicians and why these are important.

Specific Comments:

Introduction: The first portion of the introduction seems very split without coherency. The introduction starts with background on concussion testing (which precludes recent updates to the literature - i.e. the VOMS and others) and then VR testing. These two sections need to be merged together with more attention paid to why we should even care about a paradigm shift towards VR.

P5, L48: The paragraph break here is the clear split between the two ideas. The prior paragraph (L48 and above) I have seen in other papers and doesn't add much more to the literature. Please revise and emphasize the focus of the research question.

P6, L6: The citations for this section are all review articles. I would then expand on these and give some basic background as to why this is important information and what original research (not reviews) are important for this section.

P6, L16-23: This is a very long run on sentence, please adjust.

P6, L50: What is balance? What is postural control? These are very different concepts and when the authors review the Slobonouv work, they refer to postural control. Please chose 1 of the two terms and use this throughout the literature.

P7, L6: Research suggests, never "shows". Please revise.

P7, L18: Is there a scale or reporting system used by Slobonouv? If so, report it and indicate why it is important.

P7, L21: What is COP Coherence? The authors cannot assume that average clinicians

understand this term. Please define and explain.

P7, L30: Define "moving room" - again make the information relevant to your readers.

P8, L6: Balance or postural control? Please specify

P8, L40: Provide a paragraph break between Wii Basic Balance Test and Wii Soccer Heading Game. Provide a transition statement between the items discussed.

P9, L8: This sentence is very confusing as written. What does "except for the environment..." indicate? Please revise.

P9, L33: Please remember to define specific jargon such as "inhibition".

Table 1: This is a very nicely formatted and straight to the point table. The only suggestion is to add in a column (or create another table) that outlines the diagnostic accuracy or reliability/validity statistics.

Discussion: This section is the most concise and helpful section of the article. The only aspect that is missing is a section discussing the clinical relevance along with limitations of the review. Please add both in for a more comprehensive understanding of the data.

#### Reviewer #2: General Comments:

This article flowed well and was easy to understand from a clinician's point of view. The graphical abstract was well done and created interest to read further. As a literature review, there were some sections that warranted further comment as it leaves the reader wondering how VR can make claim to have cognitive measures without revealing a synopsis of that specific method.

#### Specific Comments:

Introduction: The mechanism of SRC is very brief and incomplete. It would be good to expand on this as to what happens to the brain tissue within the cranial cavity and the effects on the cognitive and vestibular function as well as the ocular-motor system to clarify which post injury assessments address specific neural deficits with SRC.

P5, L43: Clarification is needed here. The sideline or acute screening tools are also the assessment tools for recovery. Both the acute and recovery tools could use improvement.

P6, L16-26: The reference indicated here that VR can help with cognitive and behavioral assessments but then there is no mention of this in the rest of the paper. As a clinician, I would be interested to know what the method for this is. The explanations the VR testing methodology later in the paper with citations of specific VR methods with respect to reactions to the VR environment or a description of the actual methods of the specific test would be good here as well.

P8, L1-58: This is confusing as this is inferring that these studies are in a VR environment. These students were not done in a complete VR setup but rather on a video screen with eye tracking equipment. An explanation of the difference between complete VR and augmented VR would be good here.

P7, L6: Research suggests, never "shows". Please revise.

Table 1: The table is well formatted and provides quick summary of the literature review.

#### Discussion:

P13, L33-45: This is an example of where a previous explanation of what the difference is between a complete VR immersion setup is and an augmented VR equipment setup would be helpful to the reader. The way it reads earlier, it sounds like they are the same.

#### Emerging VR Concussion Management Tools

P13, L52-60: Starting at "The aim", this is awkward. Please consider revising.

P13-14: L60: Expand on the "Eye-Sync" system as was done with "HeadRehab" VR system.

Conclusion:

This is very brief. Try referring back to each type of VR system, how those models can fit in the clinical setting and expand on this. This is where the clinician is looking for guidance and suggestions based upon the various VR options and the research behind them.

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Author's response

Dear Dr. Nicholas G. Murray,

Please find attached our revised manuscript entitled "Virtual Reality in Concussion Management: From Lab to Clinic". We appreciate the careful reviews and constructive feedback provided by the reviewers. We have carefully modified the manuscript in response to their suggestions.

Our point-by-point responses to the reviewers' comments are provided below. In the revised manuscript, the changes or additions are made by using red font.

We believe the manuscript is substantially improved through this peer review process. It is our hope that you will find this revised manuscript suitable for publication, it will be of broad interest to the medical and scientific community, and that it will contribute to the objectives of Journal of Clinical and Translational Research.

Sincerely, Jaclyn Caccese, Ph.D. (on behalf of our coauthors)

Reviewer #1: General Comments:

Overall, this article is well written with some interesting information that is somewhat relevant to the field of study. One major concern is that the authors are differentiating between what is augmented versus virtual reality. Many assessments noted by the authors are using augmented reality (see specific comments) and these are typically game-like interfaces (i.e. any wii gaming based assessments) as compared to fully immersive environments that block out all external stimuli.

Authors' Response: We greatly appreciate your time in reviewing this manuscript and have tried to address your comments provided. Specifically, you will notice we have revised the introduction to include a working definition of virtual reality (VR), augmented reality (AR), mixed reality (MR) and extended reality (XR). "Extended reality (XR) is the use of all virtual and human-machine interactions. XR is the combination of virtual reality (VR), augmented reality (AR), and mixed reality (MR). VR can be defined as computer-generated simulated environments in real or imagined worlds. In VR, the user is able to interact with the virtual environment without using visual cues from the real world, sometimes, but not always, using digital recreations of his/her body (i.e., avatars). VR technologies include standard computer monitors, surround-screen displays, head-mounted displays, and dome-type projections. AR can be defined as the projection of virtual objects into the real world. In AR, the user is not able to interact with the virtual overlay of digital information in the real world. AR technologies most commonly include smartphones, although some head-mounted displays and/or smart glasses are available. MR is a combination of VR and AR. In MR, the user can see the virtual object being projected into the real world and can interact with it. For example, a user can touch or grab a virtual object using his/her own hand." Considering the rapidly evolving landscape of VR, AR, MR, XR, we acknowledge that there may be some differing

opinions regarding these definitions, but nonetheless, we hope that this review makes a significant contribution to establishing a justification and framework for future VR concussion research.

The second major concern for this article is the lack of a methods section. It is completely understandable to have a non-systematic literature review, however, some aspect of a methods section should be included in the article. For example, which search engines were used, how articles were selected (inclusion/exclusion criteria), and search terms is required. Please add this important section to the manuscript.

**Authors' Response:** We appreciate your valuable feedback on this manuscript; however, according to the JCTRES Author guidelines ([https://www.jctres.com/media/filer\\_public/3d/f2/3df2cd48-467f-42bf-bc726ed67e3fc5b2/jctr\\_guideline\\_-\\_types\\_of\\_reviews.pdf](https://www.jctres.com/media/filer_public/3d/f2/3df2cd48-467f-42bf-bc726ed67e3fc5b2/jctr_guideline_-_types_of_reviews.pdf)), a literature review is a generic term used to describe published materials that provide examination of recent or current literature. The search may or may not include comprehensive searching and the analysis may be chronological, conceptual, thematic, etc. Therefore, we did not feel it was required to provide a methods section. Our aims/scope differ from a meta-analysis or systematic review, which requires exhaustive, comprehensive searching.

Third less severe concern is that the discussion should include how this information is relevant to clinicians. This article contains a high amount of jargon and some of that is not translatable to athletic trainers or other clinicians. Please tone down or define the jargon across the entire manuscript while simultaneously adding in or clarifying in the discussion what tools/items/other are currently available for use for clinicians and why these are important.

**Authors' Response:** The discussion outlines advantages and challenges of VR implementation, as well as emerging VR tools. We have added a paragraph providing additional "best practices" of VR implementation, including targeting specific outcomes of interest and obtaining training in each VR tool. Unfortunately, there is only limited work in this space within the context of concussion. The goal for this review is to encourage researchers and clinicians to continue to explore VR as an assessment and rehabilitation tool for concussion. We have also tried to define jargon when used, including adding an introductory paragraph providing a definition of VR.

**Specific Comments:** Introduction: The first portion of the introduction seems very split without coherency. The introduction starts with background on concussion testing (which precludes recent updates to the literature - i.e. the VOMS and others) and then VR testing. These two sections need to be merged together with more attention paid to why we should even care about a paradigm shift towards VR.

**Authors' Response:** After considering your first major concern (i.e., differentiating VR, AR, MR, XR) and your comment provided below (e.g., the introductory paragraph does not add much to the literature), we have decided to remove the introductory paragraph and add a working definition of VR, AR, MR, XR. As such, the entire introduction has been revised.

P5, L48: The paragraph break here is the clear split between the two ideas. The prior paragraph (L48 and above) I have seen in other papers and doesn't add much more to the literature. Please revise and emphasize the focus of the research question.

**Authors' Response:** We have revised as suggested. Please see previous response.

P6, L6: The citations for this section are all review articles. I would then expand on these and

give some basic background as to why this is important information and what original research (not reviews) are important for this section.

**Authors' Response:** We have revised the introduction as suggested. Specifically, the second paragraph now states, "There is growing interest in VR for traumatic brain injury (TBI) assessment and rehabilitation. TBI can affect a number of different cognitive and behavioral functions and VR assessments and rehabilitation interventions can target these various domains. For example, one study assessed memory in TBI survivors and healthy age and gender matched controls with educational and occupational backgrounds similar to the TBI group. Researchers created a virtual street, which included a low distraction zone and a high distraction zone. Distractions included both visual and auditory stimuli. Participants were asked to complete memory tasks while moving along the street (e.g., complete ten errands on a checklist). As expected, the TBI group performed worse on the memory tasks and were more affected by distractions. In addition to studies examining cognitive performance in TBI survivors, other studies have examined target acquisition during reaching, postural control during standing and walking, and driving performance in individuals with mild to severe TBI. Together, these studies suggest that VR has the advantage of assessing of complex sets of cognitive and behavioral functions rather than the isolated components assessed by traditional measures. This is particularly important in understanding recovery from sport-related concussion (SRC). To date, clinical symptoms are still the best indicator of SRC diagnosis and recovery. Furthermore, competitive athletes often have cognitive and motor reserve and may not be sufficiently challenged by current assessment protocols. VR may allow for more challenging assessment protocols, while still providing precise control and standardized presentation of task stimuli and outcome measures. This review will focus on the use of VR as an SRC assessment tool.

P6, L16-23: This is a very long run on sentence, please adjust.

**Authors' Response:** We have revised as suggested the introduction, which we believe addresses this concern.

P6, L50: What is balance? What is postural control? These are very different concepts and when the authors review the Slobonouv work, they refer to postural control. Please chose 1 of the two terms and use this throughout the literature.

**Authors' Response:** Postural control is the act of maintaining, achieving or restoring balance during any posture or activity. We have chosen to use postural control throughout for consistency, as suggested.

P7, L6: Research suggests, never "shows". Please revise.

**Authors' Response:** We have revised as suggested.

P7, L18: Is there a scale or reporting system used by Slobonouv? If so, report it and indicate why it is important.

**Authors' Response:** Unfortunately, the page and line numbers for reviewers do not match our PDF submission; however, we assume this comment is in response to Slobounov's findings regarding motion sickness, dizziness, and disorientation. Although it would have been useful to report these metrics on some validated cybersickness scale, this information was not reported. Specifically, Slobounov states, "None of the subjects were able to preserve balance while viewing the 'moving room' on day 3 postinjury. This experimental condition not only

induced postural destabilization but also provoked symptoms of TBI, including motion sickness, dizziness and disorientation.”

P7, L21: What is COP Coherence? The authors cannot assume that average clinicians understand this term. Please define and explain.

*Authors' Response:* We have added, “COP coherence is a measure of the relationship between scene movement and body sway. Higher COP coherence suggests that subjects more closely match their postural responses to scene movement. Thus, the observed decrease in COP coherence suggests perceptual-motion disintegration induced by visual field motion.”

P7, L30: Define "moving room" - again make the information relevant to your readers.

*Authors' Response:* We have described the “moving room” paradigm as such, “In the "moving room" paradigm, the participant stands in a fixed inertial frame (i.e., on the ground), and the visual environment moves relative to this inertial frame (e.g., actually moving the walls of a mock room or providing a visual display that simulates such movement).”

P8, L6: Balance or postural control? Please specify.

*Authors' Response:* We have chosen to use postural control throughout for consistency, as suggested.

P8, L40: Provide a paragraph break between Wii Basic Balance Test and Wii Soccer Heading Game. Provide a transition statement between the items discussed.

*Authors' Response:* We have revised as suggested.

P9, L8: This sentence is very confusing as written. What does "except for the environment..." indicate? Please revise.

*Authors' Response:* We have clarified, “Specifically, in the VIGIL-CPT, single, randomized letters are presented sequentially on a computer screen in white, on a black background; whereas, in the Classroom-CPT, letters are presented on a blackboard in a virtual classroom that features objects and people commonly found in real classrooms, such as desks, a teacher and students.”

P9, L33: Please remember to define specific jargon such as "inhibition".

*Authors' Response:* We revised to state that the SRC group responded when it was inappropriate to do so. In other words, they were unable to suppress their responses even if they were incorrect.

Table 1: This is a very nicely formatted and straight to the point table. The only suggestion is to add in a column (or create another table) that outlines the diagnostic accuracy or reliability/validity statistics.

*Authors' Response:* We agree that the diagnostic accuracy and reliability/validity statistics are important metrics; however, few of these studies provided these measures. When available, we have included under “Findings.” Specifically, For Teel, 2016 - spatial navigation (sensitivity 95.8%/ specificity 91.4%), whole body reaction time (sensitivity 95.2%/ specificity 89.1%) and combined VR modules (sensitivity 95.8%/ specificity 96.1%) had high sensitivity/ specificity. For Murray, 2017 - the total number of levels completed (sensitivity 39.2%/specificity 82.1%), time to complete level 1 (sensitivity 87.5%/ specificity 25.3%), and level 5 completion (sensitivity 80.4%/ specificity 39.2%) had weak predicative capability (AUC<0.7). For Wright

2017 - The VETS had 91.0% accuracy and ROC AUC of 0.865, and the dynamic scene conditions, i.e., DYN-Foam and DYN-Firm, were the most discriminating conditions with and 85.9% and 87.3% accuracy, respectively.

Discussion: This section is the most concise and helpful section of the article. The only aspect that is missing is a section discussing the clinical relevance along with limitations of the review. Please add both in for a more comprehensive understanding of the data.

**Authors' Response:** We have added the following, "In the context of SRC assessment and rehabilitation, few studies have implemented VR solutions. Nonetheless, VR postural control and neuropsychological testing represents a promising next step in SRC management. VR allows for personalized interventions and may be more sensitive than traditional clinical assessments. However, VR must be implemented with caution because solutions must target specific domains. Each VR environment and application should be developed with an end user in mind; out-of-the-box or off-label VR-based tools may not target outcomes of interest. Clinicians should consider VR as another tool available to help in their assessment and rehabilitation protocols. Most VR programs are digitalizations of existing assessments, but the patient immersion in VR may result in improved ecological validity and the quantitative outcome measures may facilitate standardization. Although clinicians may be familiar with the standard version of these protocols, it is important to obtaining training in the VR-based assessments. As with any new technology, it is important to identify the advantages and challenges for implementation. Ultimately, healthcare providers trying to incorporate VR into clinical practice should consider applications best suited for their patients based on their symptoms to offer the best care possible."

Reviewer #2: General Comments: This article flowed well and was easy to understand from a clinician's point of view. The graphical abstract was well done and created interest to read further. As a literature review, there were some sections that warranted further comment as it leaves the reader wondering how VR can make claim to have cognitive measures without revealing a synopsis of that specific method.

**Authors' Response:** We greatly appreciate your time in reviewing this manuscript and have tried to address your comments provided.

Specific Comments: Introduction: The mechanism of SRC is very brief and incomplete. It would be good to expand on this as to what happens to the brain tissue within the cranial cavity and the effects on the cognitive and vestibular function as well as the ocular-motor system to clarify which post injury assessments address specific neural deficits with SRC.

**Authors' Response:** In response to Reviewer #1's concern, we have revised the introduction to focus on the definition of VR and provide specific examples of VR in TBI assessment/rehabilitation.

P5, L43: Clarification is needed here. The sideline or acute screening tools are also the assessment tools for recovery. Both the acute and recovery tools could use improvement.

**Authors' Response:** In response to Reviewer #1's concern, we have revised the introduction to focus on the definition of VR and provide specific examples of VR in TBI assessment/rehabilitation.

P8, L1-58: This is confusing as this is inferring that these studies are in a VR environment. These students were not done in a complete VR setup but rather on a video screen with eye



tracking equipment. An explanation of the difference between complete VR and augmented VR would be good here.

**Authors' Response:** We have added to the introduction a working definition of virtual reality (VR), augmented reality (AR), mixed reality (MR) and extended reality (XR). Considering the rapidly evolving landscape of VR, AR, MR, XR, we acknowledge that there may be some differing opinions regarding these definitions, but nonetheless, we hope that this review makes a significant contribution to establishing a justification and framework for future VR concussion research.

P7, L6: Research suggests, never "shows". Please revise.

**Authors' Response:** We have revised as suggested.

Table 1: The table is well formatted and provides quick summary of the literature review.

**Authors' Response:** Thank you for the positive feedback.

Discussion:

P13, L33-45: This is an example of where a previous explanation of what the difference is between a complete VR immersion setup is and an augmented VR equipment setup would be helpful to the reader. The way it reads earlier, it sounds like they are the same.

**Authors' Response:** We have added to the introduction a working definition of virtual reality (VR) to the introduction. Please see our comment above.

P13, L52-60: Starting at "The aim", this is awkward. Please consider revising. Authors'

**Response:** We have revised to, "the goal of this review was not to provide the evidence for or against any these devices..."

P13-14: L60: Expand on the "Eye-Sync" system as was done with "HeadRehab" VR system. We have added, "Eye-Sync® (SyncThink®, Palo Alto, CA) is a high-performance device that uses VR to assess abnormal eye movement. The device is portable and can be used in a clinical setting or outdoors. A person wears the VR head-mounted display and tracks a point of light to assess smooth pursuits, saccades, VOR, and VOR cancellation. In 2019, the FDA selected EyeSync® as Breakthrough Device Designation for SRC assessment."

This is very brief. Try referring back to each type of VR system, how those models can fit in the clinical setting and expand on this. This is where the clinician is looking for guidance and suggestions based upon the various VR options and the research behind them.

**Authors' Response:** The goal of this review was to highlight the potential of implementing VR in concussion assessment and rehabilitation. We have tried not to provide the evidence for or against any specific device (first due to a potential conflict of interest, but also because we have not used each device and thus cannot comment on specific advantages and challenges of each system). Instead, we urge clinicians to explore potential options and seek training, if desired.

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2<sup>nd</sup> Editorial decision

15-Apr-2020

Ref.: Ms. No. JCTRes-D-19-00038R1

Virtual Reality in Concussion Management: From Lab to Clinic

Journal of Clinical and Translational Research

Dear author(s),

Reviewers have submitted their critical appraisal of your paper. The reviewers' comments are appended below. Based on their comments and evaluation by the editorial board, your work was FOUND SUITABLE FOR PUBLICATION AFTER MINOR REVISION.

If you decide to revise the work, please itemize the reviewers' comments and provide a point-by-point response to every comment. An exemplary rebuttal letter can be found on at <http://www.jctres.com/en/author-guidelines/> under "Manuscript preparation." Also, please use the track changes function in the original document so that the reviewers can easily verify your responses.

Your revision is due by May 15, 2020.

To submit a revision, go to <https://www.editorialmanager.com/jctres/> and log in as an Author. You will see a menu item call Submission Needing Revision. You will find your submission record there.

Yours sincerely,

Nicholas G Murray, Ph.D.  
Editorial Board Member  
Journal of Clinical and Translational Research

Reviewers' comments:

Reviewer #1: Dear Authors

Thank you for amending your manuscript and I apologize for the tardiness of my review.

The additions presented considerably enhance the manuscript. Well done! You have met all of my major suggestions and made sufficient changes to the manuscript.

Thank you for allowing me to be a part of this review process.

Reviewer #2: Upon a second review of this manuscript, I again found this to be informative to clinicians who are looking into incorporating this form of technology into their practice. There is still mention of a study that did not involve VR equipment. This needs to be indicated or removed. This is in the specific line item comments below. I do feel that there were some forms of VR technology that were mentioned but warranted further explanation. An example would be the mention of "Oculus Rift" on page 12, line 40.

Specific Line Item Comments:

P.8, L1-L57: As in the previous review, this study was done without the use of virtual reality equipment. There for that should be indicated as such or removed from the manuscript.

P.9, L3-L11: A description of the equipment involved here with the ClinicaVR:Classroom CPT and the VIGIL-CPT. Not all readers may be familiar with this platform. Is the virtual classroom computer based or does it involve a headset?

P.9, L35-L40: Again, a description of the type of equipment would give a better understanding of what creates the virtual hallway.

P.12, L33-L35: This is a reference to a tool that is not considered "virtual reality".

P12, L40: The mention of "Oculus Rift" here warrants further explanation and would be good earlier in the manuscript.

P14, L4-L6: Eye-Sync is FDA approved "to record and analyze eye-tracking impairment";<https://syncthink.com/product/> This should be revised.

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Author's response

Dear Dr. Nicholas G. Murray,

Please find attached our revised manuscript entitled "Virtual Reality in Concussion Management: From Lab to Clinic". We appreciate the careful reviews and constructive feedback provided by the reviewers. We have carefully modified the manuscript in response to their suggestions.

Our point-by-point responses to the reviewers' comments are provided below. In the revised manuscript, the changes or additions are made by using red font.

We believe the manuscript is substantially improved through this peer review process. It is our hope that you will find this revised manuscript suitable for publication, it will be of broad interest to the medical and scientific community, and that it will contribute to the objectives of Journal of Clinical and Translational Research.

Sincerely,

Jaclyn Caccese, Ph.D. (on behalf of our coauthors)

Reviewer #1: Thank you for amending your manuscript and I apologize for the tardiness of my review. The additions presented considerably enhance the manuscript. Well done! You have met all of my major suggestions and made sufficient changes to the manuscript. Thank you for allowing me to be a part of this review process.

**Authors' Response:** We greatly appreciate your time in reviewing this manuscript.

Reviewer #2: Upon a second review of this manuscript, I again found this to be informative to clinicians who are looking into incorporating this form of technology into their practice. There is still mention of a study that did not involve VR equipment. This needs to be indicated or removed. This is in the specific line item comments below. I do feel that there were some forms of VR technology that were mentioned but warranted further explanation.

**Authors' Response:** We greatly appreciate your time in reviewing this manuscript and have tried to address your comments provided. To clarify, we believe that VR can include both immersive and non-immersive systems. Immersive VR systems (e.g., head-mounted displays) project the user into a 3D environment. In non-immersive VR systems (e.g., standard computer or television monitors), the user interacts with the simulated world using a device such as a controller or computer mouse. We have added these descriptions to the introduction. Additionally, we provided more details of the VR technology where suggested below.

Specific Line Item Comments:

P.8, L1-L57: As in the previous review, this study was done without the use of virtual reality equipment. There for that should be indicated as such or removed from the manuscript.

**Authors' Response:** We have added, "It is important to note that the Nintendo Wii is a non-immersive VR system, which may have affected findings."

P.9, L3-L11: A description of the equipment involved here with the ClinicaVR:Classroom CPT and the VIGIL-CPT. Not all readers may be familiar with this platform. Is the virtual classroom computer based or does it involve a headset?

**Authors' Response:** We have added that the ClinicaVR: Classroom CPT uses a virtual classroom generated in an immersive head-mounted display.

P.9, L35-L40: Again, a description of the type of equipment would give a better understanding of what creates the virtual hallway.

**Authors' Response:** We have added, "Assessments can be administered on an immersive 3DTV or in a head-mounted display."

P.12, L33-L35: This is a reference to a tool that is not considered "virtual reality".

**Authors' Response:** As we have added to the introduction, we believe that VR can include both immersive and non-immersive systems. Immersive VR systems (e.g., head-mounted displays) project the user into a 3D environment. In non-immersive VR systems (e.g., standard computer or television monitors), the user interacts with the simulated world using a device such as a controller or computer mouse. According to this perhaps lenient definition of VR, the Nintendo Wii can be considered VR. This definition is consistent with existing literature (please consider the following reference - Contribution of Virtual Reality (Nintendo Wii) for Exercise Training and Rehabilitation).

P12, L40: The mention of "Oculus Rift" here warrants further explanation and would be good earlier in the manuscript.

**Authors' Response:** The Oculus Rift has not been used to systematically assess concussion outcomes to our knowledge. We mentioned this only to provide an example of a head-mounted display. Because it was not our intention to endorse specific products, but rather to provide an overview of existing literature using VR in SRC assessments, we have removed this reference to the Oculus Rift.

P14, L4-L6: Eye-Sync is FDA approved "to record and analyze eye-tracking impairment";[https://urldefense.com/v3/\\_\\_https://syncthink.com/product/\\_\\_;!!KGKeukY!gfNO0yxXaRpCZzWnvdJYukXouLqIRzIidT4w-ubYUYhZ8ei1tXA1o-akjLn93Log\\$](https://urldefense.com/v3/__https://syncthink.com/product/__;!!KGKeukY!gfNO0yxXaRpCZzWnvdJYukXouLqIRzIidT4w-ubYUYhZ8ei1tXA1o-akjLn93Log$) This should be revised.

**Authors' Response:** Thank you for this suggestion. We have revised, "Eye-Sync® is FDA approved to record and to analyze eye-tracking impairment."

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3<sup>rd</sup> Editorial decision

21-Apr-2020

Ref.: Ms. No. JCTRes-D-19-00038R2

Virtual Reality in Concussion Management: From Lab to Clinic

Journal of Clinical and Translational Research

Dear authors,

I am pleased to inform you that your manuscript has been accepted for publication in the Journal of Clinical and Translational Research.

You will receive the proofs of your article shortly, which we kindly ask you to thoroughly review for any errors.

Thank you for submitting your work to JCTR.

Kindest regards,

Nicholas G Murray, Ph.D.  
Editorial Board Member  
Journal of Clinical and Translational Research

Comments from the editors and reviewers: