

# View Reviews

## Paper ID

2543

## Paper Title

An Effective Alignment Algorithm for Brain MRI with Outlier-Robust Wasserstein Distance

## Reviewer #3

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### Questions

**4. Please describe the contribution of the paper (a few lines).**

The paper proposes a method to align brain images based on a previously defined form of a Wasserstein metric (the Robust Wasserstein Distance). The authors incorporate the action of rigid transformations (translation and rotation) in the alignment. The paper also describes a method for computing an outlier-robust barycenter for group analysis. The authors show experimental results for alignment on brain surfaces.

**5. Please list the main strengths of the paper; you should write about a novel formulation, an original way to use data, demonstration of clinical feasibility, a novel application, a particularly strong evaluation, or anything else that is a strong aspect of this work. Please provide details, for instance, if a method is novel, explain what aspect is novel and why this is interesting.**

An interesting idea is the use of probability measures for modeling brains.

A novelty is the adaptation of the recently proposed idea outlier-robust optimal transport along with the framework defined in the FUGW algorithm for the purpose of brain alignment.

The incorporation of rigid alignment (translation and rotation)  $\$e\$$  when searching for all possible couplings for a given cost is an improvement.

The final proposed metric is a weighted combination of two Wasserstein metrics, one that matches anatomical structure, and the other that matches anatomical features.

The method is computationally efficient (on GPU) compared to one other method that the authors demonstrate.

**6. Please list the main weaknesses of the paper. Please provide details, for instance, if you state that a formulation, way of using data, demonstration of**

**clinical feasibility, or application is not novel, then you must provide specific references to prior work**

The paper doesn't do a good job of defining the notation precisely. A few terms are left undefined and unexplained. And thus, it was hard to understand the novelty of the paper immediately. They introduce the notation at the beginning of Sec. 2. However, this notation should also make the connection between surface mesh vertices and the distributions. This is completely missing.

At the onset, it was not clear if the algorithm works on intensity images or surface meshes or both. The authors show results on brain surfaces; however, they state that brain images are modeled as probability measures. It's only after going through the formulation (Sec. 3) that this method works for surface meshes. This should be explicitly stated at the beginning.

For experimental purposes, the authors use the multi-task fMRI dataset. It is assumed that the actual fMRI tasks are irrelevant for the purpose of this paper. How are the features used in  $\hat{C}$  derived? This is not mentioned anywhere, except the Dataset subsection in section 4. Otherwise, it's not clear what exactly is the gain from incorporating these features.

Are  $\{y_i\}$  the set of vertices of the target mesh? If so, it should be defined appropriately.

The composition operation  $\circ$  in  $e \circ \bar{C}$  is not defined. Is this a multiplication? Instead of computing the inner products between  $P$  and  $e \circ C$ , why not apply  $e$  to elements of  $\{y_i\}$ . I.e. incorporate  $e$  in the computation of the cost matrix?

The actual algorithm to compute the barycenter is not exactly novel. And the idea of using barycenters for group analysis has been proposed previously. The authors could cite Pennec X. (Barycentric Subspace Analysis On Manifolds, Xavier Pennec, The Annals of Statistics, Vol. 46, No. 6A, pp. 2711-2746, 2018) to motivate the barycenter.

The experimental results are not convincing. The improvement of RWD over the FUGW is not significantly higher ( $\sim 0.01$ ). Is it possible that after further fine-tuning parameters for FUGW, the correlation values may increase and be comparable to RWD?

The role of rigid transformation is not clear. Also see comments below.

**7. Please rate the clarity and organization of this paper**

Poor

**8. Please comment on the reproducibility of the paper. Please be aware that providing code and data is a plus, but not a requirement for acceptance.**

The submission does not provide sufficient information for reproducibility.

**10. Please provide detailed and constructive comments for the authors. Please also refer to our Reviewer's guide on what makes a good review. Pay specific attention to the different assessment criteria for the different paper categories (MIC, CAI, Clinical Translation of Methodology, Health Equity):**

**<https://conferences.miccai.org/2024/en/REVIEWER-GUIDELINES.html>**

The paper makes some novel contributions. However, important definitions, notations are missing. The algorithm should be properly motivated for the application. This is missing.

What is the contribution of the rigid transformation search over all elements  $\mathbf{e} \in E(\bar{d})$ ? From Table 1 and Table 2, there doesn't seem to be any difference.

Is higher correlation better? If that is the case, after adding noise, both in the cases with and without transformations, the performance seems to be going up. Can the authors clarify?

Specifically, the barycenter algorithm has also been used in the FUGW-based alignment method. The authors could also discuss the computation of barycenters in this context. This will help the reader to understand that the overall framework of matching surfaces using distributions and Wasserstein distance is borrowed from the FUGW paper, but adapted here to the outlier-robust WD.

The experimental results were not convincing. The authors should add further experiments to justify how and why RWD is an improvement over FUGW. This is not clear. Further, they should justify the inclusion of the rigid transformation term. This does not seem to affect the results.

**11. Rate the paper on a scale of 1-6, 6 being the strongest (6-4: accept; 3-1: reject). Please use the entire range of the distribution. Spreading the score helps create a distribution for decision-making (visible to authors).**

4. Weak Accept — could be accepted, dependent on rebuttal

**12. Please justify your recommendation. What were the major factors that led you to your overall score for this paper?**

This paper could have been improved significantly if the authors paid more care in precisely defining notation and other terms. Some definitions need to be explicitly stated. While the paper makes a good contribution, the clarity and readability needs to be substantially improved.

**14. Reviewer confidence: In view of your answers above and your overall experience, how would you rate your confidence in your review?**

Very confident (4)

**19. [Post-rebuttal only] After reading the author's rebuttal, state your overall opinion of the paper.**

3. Weak Reject — could be rejected, dependent on rebuttal

**20. [Post-rebuttal only] Please justify your decision**

The authors did not provide any feedback addressing any concerns.

## Reviewer #5

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### Questions

**4. Please describe the contribution of the paper (a few lines).**

This paper proposes an alignment method based on the outlier-robust Wasserstein distance under rigid transformation. The proposed method does not relies on a specified template and can generate a data specific template using the barycenter of the group as a template.

**5. Please list the main strengths of the paper; you should write about a novel formulation, an original way to use data, demonstration of clinical feasibility, a novel application, a particularly strong evaluation, or anything else that is a strong aspect of this work. Please provide details, for instance, if a method is novel, explain what aspect is novel and why this is interesting.**

1. Using the barycenter given the Wasserstein distance is a good way for the template generation.
2. The generated the template has sharper details.

**6. Please list the main weaknesses of the paper. Please provide details, for instance, if you state that a formulation, way of using data, demonstration of clinical feasibility, or application is not novel, then you must provide specific references to prior work**

1. The application of the paper is limited by the rigid transformation, because in most cases, the more complex registration is needed.
2. Some math symbols in the paper is not well explained. For example, the symbols in formula (1) is not fully covered.
3. It is not clear why definition 1 is outlier-robust.

**7. Please rate the clarity and organization of this paper**

Satisfactory

**8. Please comment on the reproducibility of the paper. Please be aware that providing code and data is a plus, but not a requirement for acceptance.**

The submission does not mention open access to source code or data but provides a clear and detailed description of the algorithm to ensure reproducibility.

**9. Do you have any additional comments regarding the paper's reproducibility?**

no

**10. Please provide detailed and constructive comments for the authors. Please also refer to our Reviewer's guide on what makes a good review. Pay specific attention to the different assessment criteria for the different paper categories (MIC, CAI, Clinical Translation of Methodology, Health Equity):**

**<https://conferences.miccai.org/2024/en/REVIEWER-GUIDELINES.html>**

1. The motivation for the method under the rigid transformation should be further discussed to justify the potential application of the proposed method.
2. Why definition 1 can lead to outlier robust needs more clear description since this part is claimed as the major contribution of the paper.

**11. Rate the paper on a scale of 1-6, 6 being the strongest (6-4: accept; 3-1: reject). Please use the entire range of the distribution. Spreading the score helps create a distribution for decision-making (visible to authors).**

3. Weak Reject — could be rejected, dependent on rebuttal

**12. Please justify your recommendation. What were the major factors that led you to your overall score for this paper?**

The potential limited application and the unclear method description.

**14. Reviewer confidence: In view of your answers above and your overall experience, how would you rate your confidence in your review?**

Somewhat confident (2)

Reviewer #6

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## Questions

**4. Please describe the contribution of the paper (a few lines).**

The paper presents a registration approach to recover rigid transformation between brain MRI scans. It introduces a outlier robust scheme derived from the Wassertein distance.

**5. Please list the main strengths of the paper; you should write about a novel formulation, an original way to use data, demonstration of clinical feasibility, a novel application, a particularly strong evaluation, or anything else that is a strong aspect of this work. Please provide details, for instance, if a method is novel, explain what aspect is novel and why this is interesting.**

- The method description is clear
- The application is relevant to the MICCAI conference

**6. Please list the main weaknesses of the paper. Please provide details, for instance, if you state that a formulation, way of using data, demonstration of clinical feasibility, or application is not novel, then you must provide specific references to prior work**

- Mismatch between the proposed method and the targeted application.
- No information is provided about other rigid registration approach.
- State of the art on outlier robust registration approach is ignored.

**7. Please rate the clarity and organization of this paper**

Satisfactory

**8. Please comment on the reproducibility of the paper. Please be aware that providing code and data is a plus, but not a requirement for acceptance.**

The submission does not mention open access to source code or data but provides a clear and detailed description of the algorithm to ensure reproducibility.

**10. Please provide detailed and constructive comments for the authors. Please also refer to our Reviewer's guide on what makes a good review. Pay specific attention to the different assessment criteria for the different paper categories (MIC, CAI, Clinical Translation of Methodology, Health Equity):**

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The paper is well presented and easy to follow until the experiment section. I think however that the overall method is somehow lacking depth and the arguments are somewhat contradictory in places. For example: One argue that outliers can impact registration results for brain MRI application, yet the authors later state that an imperceptible amount of outlier was present. Why then develop an outlier robust scheme for an application that does not exhibit any? One argue against between potential morphometric difference between population, but only focus on rigid transformation optimisation.

Many other approaches have been presented for outlier-robust rigid/affine registration, that are of particular interest when part of a structure is missing (e.g. pre/intra/post surgery). One example, amongst others, is the simple block matching approach combined with a least trimmed square. This approach can in theory deal with up to 50% outliers, here the authors add noise to 1.4% of their data.

I found the validation rather complicated to follow.

If a Pearson coefficient is the best measure to quantify the quality of the registration, why don't the authors optimise this instead?

Why is there a mention of a training/validation/testing split here?

What does it mean to use the dataset with or without rigid? Especially when the result presented in table 1 and table 2 are close to identical.

Why would it make sense to compute the geometric centre from 13 different subjects and expect well aligned barycentres when only rigid transformations are used?

**11. Rate the paper on a scale of 1-6, 6 being the strongest (6-4: accept; 3-1: reject). Please use the entire range of the distribution. Spreading the score helps create a distribution for decision-making (visible to authors).**

2. Reject — should be rejected, independent of rebuttal

**12. Please justify your recommendation. What were the major factors that led you to your overall score for this paper?**

Overall, I do not thing the investigated application demonstrates the potential benefits of the proposed method.

**14. Reviewer confidence: In view of your answers above and your overall experience, how would you rate your confidence in your review?**

Very confident (4)

**Reviewer #7**

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**Questions**

**4. Please describe the contribution of the paper (a few lines).**

The work describes a method to perform rigid transformation using a modified Wasserstein Distance that is robust to outliers. The rigidly aligned samples are used to compute barycenters for the group.

**5. Please list the main strengths of the paper; you should write about a novel formulation, an original way to use data, demonstration of clinical feasibility, a novel application, a particularly strong evaluation, or anything else that is a strong aspect of this work. Please provide details, for instance, if a method is novel, explain what aspect is novel and why this is interesting.**

- RWD defined specifically for aligning fMRI data

**6. Please list the main weaknesses of the paper. Please provide details, for instance, if you state that a formulation, way of using data, demonstration of clinical feasibility, or application is not novel, then you must provide specific references to prior work**

-lacking statistical analysis and p-values for all experimentation

- ablation study of the wasserstein distance with and without the robustness guarantee mechanism

**7. Please rate the clarity and organization of this paper**

Very Good

**8. Please comment on the reproducibility of the paper. Please be aware that providing code and data is a plus, but not a requirement for acceptance.**

The submission does not mention open access to source code or data but provides a clear and detailed description of the algorithm to ensure reproducibility.

**9. Do you have any additional comments regarding the paper's reproducibility?**

- love to see the RWD being released as a package

**10. Please provide detailed and constructive comments for the authors. Please also refer to our Reviewer's guide on what makes a good review. Pay specific attention to the different assessment criteria for the different paper categories (MIC, CAI, Clinical Translation of Methodology, Health Equity):**

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- would ideally compare FUGW and RWD on the same device, so the time metric is actually irrelevant even though RWD is faster on the CPU than FUGW on GPU. Also the time metric must be mean  $\pm$  std calculated over multiple samples.

- I think there can be different kinds of noise, additive noise is limited and does not give value; also multiple additive noise should have been used instead of just 0.014.

- lacking statistical analysis and no p-values to give significance of the results.

**11. Rate the paper on a scale of 1-6, 6 being the strongest (6-4: accept; 3-1: reject). Please use the entire range of the distribution. Spreading the score helps create a distribution for decision-making (visible to authors).**

4. Weak Accept — could be accepted, dependent on rebuttal

**12. Please justify your recommendation. What were the major factors that led you to your overall score for this paper?**

The paper is easy to understand. The problem is well explained along with the mathematical formulation is clearly given for each and every step. The method outperforms the nearest method.

**14. Reviewer confidence: In view of your answers above and your overall experience, how would you rate your confidence in your review?**

Confident but not absolutely certain (3)