Examiner's Report

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Rock and Roll: The Effects of Centre of Mass Movement and Bicycle Lean on the Biomechanics of Cycling

General

The research presented in this doctoral thesis represents a substantial contribution to our understanding of the biomechanics of bicycling – one of our most common forms of transportation, and a popular recreational and competitive activity. The biomechanics of cycling has been studied for decades, yet this thesis breaks new ground both in terms of the novelty of the analyses and the ecological validity of the protocols employed, providing new insights in the process. Overall, I feel that this work meets the standards normally associated with doctoral theses at internationally renowned research universities. However, there are numerous places where the document should be strengthened and the writing made clearer. In this report, I have provided several major and minor comments that I feel should be addressed before the thesis is finalized.

Two general comments that apply throughout the document:

In most parts of the document the author refers to "energy transfer" but in a few places the phrase "power transfer" is used. I appreciate the latter term sometimes appears in the literature, but in most cases "energy transfer" is the more appropriate term as power itself already refers to a flow of energy (what does it mean to transfer a flow?)

According to the S.I. standard, when units are written out (watt, newton) lowercase should be used. Upper case is reserved for the proper nouns.

Chapter 2 (Literature Review)

Overall, the literature review well written and does a nice job of covering the relevant background literature. I have only one major and one minor point.

The purported transfer of energy by muscles described by van Ingen Schenau and colleagues, and that described by Zajac and colleagues are quite different, with the former being developed in terms of joint power, with the latter describing effects on segment energy. This can lead to opposite conclusions about the direction of energy flow (proximal-to-distal or distal-to-proximal) as described by Pandy and Zajac in their papers on jumping from the early 1990s (see also van Soest et al. 1993). The literature review includes a section describing the Zajac approach, but in the other chapters it seems the descriptions are more aligned with the van Ingen Schenau approach (e.g., "power produced by knee extensors being transferred by bi-articular muscles to the hip and ankle"). This issue could be addressed by describing both approaches in this literature review.

The citation of Marsh et al. about joint-moment minimisation, muscle power, gross efficiency, is not really appropriate to cover all of these various performance criteria. Instead, I suggest consulting the review on preferred cadence by Martin et al. (2000, *The Encyclopedia of Sports Medicine: Biomechanics in Sport*, pp. 143-160).

Chapter 3 (The Mechanics of Seated and Non-Seated Cycling at Very-High-Power Output: A Joint-Level Analysis)

While the concept of effective mechanical advantage was described in the literature review, it appears for the first time in this chapter in the purpose statement near the end of the introduction section. It would be helpful for the reader of this chapter to describe this concept and explain why it is important for understanding the mechanics of high power output cycling.

When the author refers to "redistribution of joint power" (e.g., third paragraph of introduction section) is this meant to imply among joints, or from positive to negative within (or between) joints? Given some of the findings, being clearer about this would be helpful for the reader.

No justification was provided for the sample size of fifteen subjects. What was the basis for deciding on this sample size? Further, what are the implications of mixing cyclists and both competitive and recreational non-cyclists into the sample? It may be more appropriate to address this in the discussion section, but what does the literature tell us about difference, if any, in pedaling mechanics between cyclists and non-cyclists?

The text in Table 1 is so small as to be almost illegible. This table needs to be reformatted so as to be easier to read, perhaps using a landscape orientation.

It is unclear as to whether "lower limb power" includes the power associated with the linear velocity and net joint force at the hip, though I suspect not. Including this power term would help address the uncertainty about the "contributions of power from the upper body and upper limbs" (both quotes from page 42 in the results section, but also mentioned in the discussion section). See for example, Broker and Gregor (1994, Med Sci Sports Exerc 26: 64-74). Please clarify this point appropriately, depending on its inclusion or exclusion in the analyses.

The passage in the first paragraph of the discussion section on greater ankle muscle power without an increase in muscle activation would benefit from a muscle mechanics-based explanation.

In the summary paragraph it is stated "This coordination strategy and increase in EMA at the knee joint means it is likely that both non-muscular and muscular power is more effectively transferred to the crank compared to when seated." The muscular power has been well described to this point, but it would be helpful for the reader to be more explicit about how increased knee joint EMA leads to more effective use of non-muscular power, if that is what was actually intended.

Chapter 4 (Riders Use Their Body Mass to Amplify Crank Power During Non-Seated Ergometer Cycling)

In both the introduction and discussion sections it is noted that the vertical motion of the COM in non-seated pedaling may be beneficial, and in the discussion section the connection to reducing the metabolic cost of pedaling is made. It seems worth noting that if the crank work derived from the COM is metabolically beneficial, that is probably only true for a narrow range of vertical oscillation amplitudes. There are relevant analogs from the human walking literature about variations in COM motion and metabolic cost (e.g., Ortega & Farley, 2005, J Appl Physiol, 99:2099-2107).

In the introduction section when it is mentioned that “riders appear to utilise this non-muscular contribution to crank force by lowering their preferred cadence” it is not clear in this passage how cadence factors into exploiting non-muscular contribution. Please clarify.

In the followings passage from the results section, should it be “without an equivalent increase in kinetic energy” rather than “decrease”? *Likewise, substantial decreases in potential energy occurred during the second half of each leg’s downstroke (90-180°) without an equivalent decrease in kinetic energy, meaning energy of the CoM was most likely transferred to the crank*.

The wording used in the second half of the third paragraph (p. 64) is confusing for the reader, in part by invoking momentum in a study about work and power. The other issue is describing how the forces the arms apply to the handlebars ensure that the lower body does not raise the COM, when in fact that is what the entire study is about. Consider rewriting this passage for greater clarity.

The paragraph on muscle passive elastic energy in the discussion seems inadequate in substance. How would it be possible to determine if COM energy was being stored in muscle elastic elements and used later to provide crank power? Every time a muscle produces force, even isometrically, the tendinous tissues are stretched, storing mechanical energy, that is then released when the muscle relaxes.

Chapter 5 (The Effect of Bicycle Lean on the Mechanics of Non-Seated Cycling)

Compared with the first two studies, the chapter describing this study is less well developed. For example, the analogy of riding a horse should be introduce earlier in the introduction and better explained, rather than being embedded into the final sentences of the introduction. Likewise, in discussing bicycle lean, the author only seems to consider lean versus no lean. What about exaggerated lean, beyond what cyclists naturally do? If there is an ideal amount of lean, either mechanically or metabolically, it is surely influenced by what happens with both more and less lean, which may have quite different effects.

For the benefit of the non-expert reader, in the methods section, please briefly explain the differences between the rollers and the trainer. Then in the discussion section, please briefly explain why the lean angle was not zero for the trainer.

Consider revising the phrasing “using the arms to either resist or cause accelerations of the CoM” (p. 70) as it does not make sense mechanically. Any force will always tend to cause an acceleration.

Consider splitting Table 5.1 into two or more tables. The text is so small as to be difficult to read.

How large a limitation was it that riding on rollers was a novel task for some, but not all, of the participants? Further consideration of this issue is warranted.

In the statement “We interpret these results as evidence bicycle lean plays an important role in facilitating the production of high pedal force and power during non-seated cycling …” there seems to be the need to provide the qualifier “when no lateral support is provided” (such as by the trainer). In general, the results obtained on the trainer are not well integrated into the discussion. For example, what are we to make of the similarity of results between leaning on the rollers and riding on the trainer?

Please more fully explain for the reader the basis for inferring that radial crank force and handlebar force are primarily used to perform work on the COM. (3rd paragraph of discussion, p. 82).

The summary paragraph should contain a brief, self-contained, explanation for the statement that "leaning the bicycle during non-seated cycling allows a greater non-muscular contribution to crank force and power" that is directly based on this findings of this study.

Chapter 6 (Discussion and Summary)

Overall, this section reads well and does a good job of summarizing the work and suggesting future directions. Some of my earlier comments on Chapters 3-5 apply to section 6.1 and I won't repeat them here. Two additional, specific comments. Section 6.2.1: While there are no impacts in cycling as there are in walking, there is the possibility that energy is dissipated through various pathways. It is not necessary that all reductions in COM energy have to either be transferred to the cranks to be stored in tendons. Section 6.3.1: In the first paragraph, there is no evidence that cyclists have actually "maximized" non-muscular forces by leaning the bicycle.