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Comparing Traditional and Novel Methods in Determining Reach in Bicycle Fitting

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ABSTRACT: In bicycle fitting, the literature has focus historically on the saddle height and knee flexion angle. There has been little focus in the literature on postural reach; this is the distance between the saddle and handlebars. Currently, this distance is determined by a specialist, a *bicycle fitter*, and is generally based on a trunk, shoulder, and elbow angle; however, it is primarily based on what "looks right" to the fitter and "feels right" to the client, rather than using anthropometric measurement. This study examined whether there was a relationship between anthropometric measures and postural reach, or if ideal fit should continue to be determined by a trial-and-error process, informed by expert opinion and client feedback. This study found that there was a moderate correlation $r(9) = 0.663$, $p < .05$ between the upper extremity measure and postural reach and a fair correlation $r(9)= 0.296$, $p < .05$ between the trunk measure and postural reach. A significant regression was found between the upper extremity length and the postural reach $F(1, 9) = 7.06$. The finding of this study does suggest that there is a relationship between the anthropometric measures and the postural reach. However, due to the low number of data points, the external validity may be somewhat limited, and it is suggested that the study be only used as a guide for future exploration**.**

KEYWORDS: bicycle fitting, postural reach, ideal bicycle fit, sports research, human subjects

I. INTRODUCTION

A national survey found that 18% of the population that were 16 years or older used a bicycle at least one time during the summer of 2012[1]. Of those who rode their bicycle, 33% rode for recreational purposes, 28% for exercise or health, 17% for errands, 8% to visit friends, 7% commuted for work, and 4% commuted for school. The average trip length was 65 minutes, with 42% lasting less than 30 minutes[1]. This demonstrates that while riding time varies between cyclists, most riders spend a reasonable amount of time in contact with their bicycles.

When on a bicycle, the rider has multiple points of contact. These points of contact include the hands, the buttocks, and each foot. In many cases, these points of contact become relatively fixed and possibly become points of pressure and friction. These contact points, and the surrounding joints, can become areas of discomfort for many riders. While on the bicycle the cyclists have tried to adapt their bodies to the bicycle instead of the bicycle to their bodies. It seems reasonable to think that these areas of contact can lead to non-traumatic overuse injuries. Dettori and Norvell[2] reported that non-traumatic overuse injuries are a common complaint among cyclists, with the projection that 85% develop one or more injuries within their lifetime. However, because these types of injuries are not always reported, the true frequency of non-traumatic injury is not really known[2].

The most common sites of injury that cyclists report include the knees, lower extremities, the neck and shoulders, the low back, the perineum and buttocks, and the wrist and hands[2]. The areas of reported non-traumatic injury coordinate with the areas of contact that cyclists have with their bicycles. Currently, as many authors have confirmed, there is insufficient literature to make the connection between these injuries and a poor bicycle fit[2,3].

Bicycle fitting has historically been a process-based mostly on opinion and empiric methods; much of what has been studied and reported has focused on how to produce the maximum power output on a bicycle with the least metabolic cost[4]. An often overlooked author himself, Too did attempt to track down the sources for some of the standard measurements and approaches that are still practiced with contemporary cycling[4]. Even many of Too's citations are from the late nineteen-sixties and early nineteen-seventies and not from peer-reviewed journals[4].

Since the development of the bicycle, people have been trying to not only go faster for longer periods but also to maintain greater comfort while they ride. The first bicycle looked much like a strider bike that you might see a small child using as their first bicycle today; it had hard wooden wagon-like wheels, a plank seat, and was powered by walking your feet along the ground[5,6].

Since the earliest bicycle, there have been several advances in how people approach the sport as well as technological advances that have improved bicycles. Over time these improvements have included the addition of pneumatic rubber tires, seats with padding, and suspension, all of which have improved comfort on a bicycle. Other important improvements have included adding a chain and cog system that allowed the rider to pedal the bike[5]. It is unclear if, during this early period, the concept of a bicycle fit was considered. Bicycles were produced in relatively low numbers and seen as more of a utilitarian or novelty item.

With the introduction of mass production, bicycles are engineered to fit many, though riders come in all shapes and sizes. Historically riders have had to adapt themselves to their bicycles depending on what the manufacturers built. This has created issues with comfort on the bicycle as well as possibly limiting the riders' ability to deliver the power of their legs to the wheels. Because of the limitations of the manufacturing process, the bicycle needs to be adjustable in order to accommodate different body types. While bicycles have become increasingly customizable, for example, they now have adjustable seats and handlebars, there is no scientific approach that has been established to promote the ideal fit and biomechanics that would prevent repetitive stress injuries[2,7].

Much of the knowledge regarding bicycle fitting is related to the attempts to improve on this "one size fits all" nature of the bicycle. Many of the adjustments that are currently made have been determined empirically, rather than via scientific inquiry[8]. Pruitt and Matheny[9] outlined some general rules of bike fitting. The first rule is that the bike fit should be viewed as creating a marriage between the rider and the bicycle. The second rule is that the bike should fit the person; the person should not make themselves fit the bike. The third rule is to try to and perform a dynamic bike fit instead of a static fit, if time and equipment allow. Rule number four is to remember that bicycling is a highly repetitive activity. The rider may spend many hours on the bicycle in the same position and repeats the same motion. The final rule is that the process of fitting involves a "fit window" where the rider is positioned correctly and comfortably, and that this window may change over time as both riders and the bicycles they use change[9]. Pruitt and Matheny's work demonstrates how bicycle fitting has been managed historically[9]. However, the field needs an evidence-based approach to begin to determine what makes for an individual's ideal fit.

II. RESEARCH PROBLEM

The problem is that the current research in bicycle fitting that examines postural reach has only contributed to an understanding of how to find postural reach based on subjective measures[10]; however, little research has been conducted into the utilization of anthropometric methods to determine postural reach. What would be useful is to determine whether there is a correlation between anthropometric measures and postural reach. It appears plausible that the use of anthropometric measures may provide a better initial approximation, or *fit-window*, for finding postural reach with less effort on the part of fitters and clients. If there is a correlation between the anthropometric measures and reach, this would allow for the determination of a regression equation that will help identify the fit window for postural reach. This equation would provide the fitters with a better starting point for determining reach than what currently amounts to an educated guess[11]. If found, this correlation could allow for improved fit, comfort, and possibly help improve the link between fit and non-traumatic stress injuries.

The purpose of this quantitative retrospective correlational study was to determine whether there was a correlation between the anthropometric measures of upper extremity and trunk length and postural reach. This study provides an entry point to begin to examine what makes a good bicycle fit and in the future help with the connection between a poor fit, or lack of fit, and injury. The data for this study was a retrospective sample of convenience. The participants were 11 cyclists in the Pacific Northwest region of the United States (U.S.) who had undergone a bicycle fitting by three licensed physical therapists at their outpatient clinic. The anthropometric and reach measures were taken from the client chart, and a correlation was performed on the data to look at the relationship between their anthropometric measures and the reach that was determined during the fitting. When it was determined that a moderate to strong correlation existed, a multiple regression was used to develop an equation for determining a reach fit window.

This quantitative retrospective correlation study addressed the following research questions:

RQ1. Is there a moderate to strong correlation between the reach determined during bicycle fitting and the anthropometric measures of upper extremity length and trunk length?

RQ2. If a correlation does exist between the anthropometric measures and the reach, can a regression formula be determined that accurately describes this relationship?

Hypotheses

Two methods for determining reach were compared: the traditional reach method and the use of anthropometric measures:

H_{01}. There is no relationship between the reach determined by the traditional reach method and anthropometric measures.

H_1. A positive correlation exists between the Traditional reach method and Anthropometric measures.

If there is a correlation between anthropometric measures and postural reach, then a reach prediction equation should be determined based on the regression of variables gathered during the fitting.

H_{02}. That postural reach cannot be determined via an equation.

H_2. That postural reach can be accurately predicted using a combination of variables.

III. LITERATURE REVIEW

Non-traumatic Overuse Injuries

Little literature ties improper riding position to overuse and repetitive stress injuries, other than those that simply state what the most commonly observed injuries. Injuries in cycling fall into two categories: traumatic and non-traumatic[12]. Non-traumatic injuries are the focus of this study. Non-traumatic injuries can be divided further into two main categories. These categories are contact injuries and overuse injuries. Contact injuries are issues that can occur at the points of contact between the bicycle and the rider. These problems are usually due to errors in choices of equipment or to poor bicycle fit. Overuse injuries are theorized to be caused by either training errors or poor bicycle fitting[12].

Overuse injuries are defined as nontraumatic injuries that cause pain and discomfort[3]. They are not associated with the normal aches and pains seen with riding, and they often require follow-up with a healthcare professional. Unfortunately, many people conflate nontraumatic injuries with what they might consider "normal" aches and pains. For many, the act of riding a bicycle is seen as an inherently uncomfortable or even possibly painful activity[3].

Bicycle Performance and Comfort

Dorey and Gaustavino looked at how the idea of comfort on a bicycle appeared in popular American bicycle magazines and in online forums[13]. A view exists that comfort, speed, and performance on a bicycle cannot co-exist. If you are fit for comfort on a bicycle, this prevents you from going fast or decreases performance. On the other end of the spectrum, any fit that has the goal of speed and performance will produce a position that is uncomfortable[13].

Like any other sport, people are bound to experience some discomfort when they first start a new activity or with the change of a parameter of a currently performed activity such as intensity, resistance, or duration. In most cases, this pain is delayed onset muscle soreness[5]. DOMS starts and peaks within the first 24 to 72 hours after an activity. It has been seen to last between 5-7 days with pain and stiffness within the muscle. The cause of DOMS is thought to multifactorial[3,5].

A non-traumatic or overuse injury can initially feel very similar to DOMS. Many cyclists face the challenge of trying to differentiate between DOMS, soft tissue familiarization with equipment, and factors that need to be addressed, such as the non-traumatic contact and overuse injuries[12].

Comparison of Nontraumatic Overuse Injury by Rider Skill Level

When looking at the spectrum of cyclists, Priego et al. suggested three categories based on cyclists' purposes for riding[14]. First, there are elite riders who focus on professional competition. The next category is comprised of club riders whose focus is recreational competition. These club riders can be further divided into ranks based on skill level. This ranking goes from category four riders, who are new to competition, to category one riders, whose abilities are just below the elites. Last, there are enthusiasts or recreational riders who do not focus on competition.

Elite riders. When looking at literature examining nontraumatic injuries in elite riders, there is a general pattern that can be seen. In almost all of the studies, the knees were the area that most riders reported as a site for nontraumatic injury[3,5,7,10]. The next area that was reported is a little more difficult to classify as some authors report the low back[3], while others report issues as occurring more generally in the spine[15].

Club-level cyclists. When looking at overuse injuries among club-level cyclists, or competitive recreational riders, there is little published data. This is perhaps because these riders become hidden within the two other groups: the competitive professional and the non-competitive recreational riders. As an example, Bakker et al. defined competitive recreational riders as *amateurs* (though this terminology is associated with varying skill levels across the sport) and non-competitive recreational riders as *fun-riders*[16]. The issues reported for the competitive recreation rider are not well delineated as the authors only identified sensation associated with nontraumatic injuries as either "pain and discomfort" or "knee pain" [16]. The first category, "pain and discomfort," included any issues that were not related to the knee[16]. Dahlquist, Leisz, and Finkelstein reported findings collected from club riders that support the pattern of the knee and low back being the most common areas[17]. These findings are further supported by a published abstract from an oral presentation, reporting the low back and knee as the most common areas reported in a survey of 15 non-professional cycling clubs[18].

Recreational riders. When looking at non-competitive recreational riders, all of the information that is published comes from subjects who were recruited when they had taken part in organized cycling rides. While the results vary slightly between authors, the knees are reported as one of the most common areas where non-competitive recreational riders develop non-traumatic injuries[19,20]. Overall these authors also reported a greater variety of other areas of issues when compared to the competitive professionals and the competitive amateurs. The areas reported include hand/wrist, neck, shoulder, buttock/groin region, and foot/toes[19,20].

As the literature demonstrates, non-traumatic repetitive stress injuries or overuse injuries occur in cyclists of all levels. Consideration of the various reports about non-traumatic repetitive stress and overuse injuries provides a contextual backdrop for interpreting the historic CONI Manual about the possible connection between poor adjustment leading to discomfort, pain, and possible injury[12]. While bicycle fitting is a suggested strategy to address these issues, no direct connection between correcting these issues and preventing injuries has been identified[2,7]. A recent study by Priego Quesada et al. began to show increased comfort on the bicycle with fitting, though they still note the missing link between fitting a cyclist and decreased injuries[14].

Bicycle Fitting

The actual history of determining a rider's position and performing a bicycle fit for an individual remains a little murky, with the techniques and standards still set solely by expert empiricism. One of the earliest consolidations of this knowledge appears in the CONI manual[12]. Written by a group of experts, the manual covers a number of topics that include frame building, training, nutrition, and guidelines for positioning standards. Though not all areas that are examined in a modern bicycle fit are included, and in some cases, only vague explanations are provided[12]. Ultimately, the manual does not provide any actual techniques of how to perform a fitting.

Succeeding texts that cover bicycle fitting start to provide more concrete guidance, techniques, and standards for fitting[4,8]. However, the authors' standards are not supported by published literature and are rather based on expert opinion. Too[4] showed what literature did exist to support the fitting process focused most on performance measures and the metabolic changes that take place with cycling and how to make cycling more efficient. Again, many of the author's citations regarding fitting are from the late nineteen-sixties and early nineteen-seventies and are not from peer-reviewed journals[4].

Because of this dearth of scholarly resources, the field has developed bicycle fitting upon the basis of the leaders in the sport and the opinion of experts. These opinions have begun to appear in scientific journals over time. From this knowledge base, the modern concept of bicycle fitting has evolved. These sources did not look at the kinetics and kinematics of cycling, mainly for the simple reason that they did not yet have the technology and tools needed to easily and directly measure the movements and forces of cycling. Instead, the authors were limited to examining the forces mathematical.

The Bicycle

A bicycle fitting starts with the selection of the size of the frame and the style of the bicycle. The size of a frame is determined by measuring from the middle of the bottom bracket to the top of the seat tube, which is either the actual top of the seat tube or where the top tube and seat tube intersect. This seat tube measure is the only measurement that is standardized in the industry. All other dimensions of a bicycle, including the length of the various tubing and the angles where they intersect, do not meet any standard guidelines. These dimensions depend mostly on style and the manufacture's preferences. The dimensions can effect stability, feel, and bicycle control. The style of bicycle helps determine some of the dimensions, design, and riding position. What is sometimes referred to as a city bicycle will usually have a more relaxed upright position compared to a road racing bike that has a more aggressive forward flexed position[7].

IV. METHODOLOGY

The purpose of this retrospective quantitative correlational study was to determine whether there is a correlation between the anthropometric measures of the upper extremity and trunk and the postural reach. When it was determined that a moderate to strong correlation did exist, a multiple regression was used to develop an equation for determining a reach fit window. The method for determining reach during a bicycle fitting is not well defined. This study aims to identify if a correlation exists between the reach that a fitter determines and a client's upper extremity and trunk length. If that relationship exists, it should be possible to develop a regression equation that describes this relationship and provide the fitter with a starting point to determine the reach component of the fitting process.

A. *Participants*

The eleven subjects selected were a sample of convenience, drawing data from those clients who were seen by three licensed physical therapists at their outpatient clinics and requested a fitting, or who had a fitting as part of their treatment plan. The exclusion criteria included cyclists who were being fitted in the aero position on their triathlon bicycle, which is an aerodynamic position that allows the rider to rest on their elbows rather than their hands. Three local physical therapists, known to the primary investigator, who perform bicycle fittings as part of their regular client services.

B. *Data Collection*

Three local physical therapists, known to the primary investigator, who perform bicycle fittings as part of their regular client services, were recruited via email. All three agreed to participate. The three treating therapists retrospectively gathered the data from the charts of participants who had previously undergone a bicycle fitting using their normal fitting process. All the data entered by the treating therapist into an Excel spreadsheet coded to preserve the participants' privacy. Demographic information necessary to the study included age, gender, years of experience, and bicycle make and model. The fitting process included the determination of saddle height, saddle fore-aft, fitter determined reach (Figure 1, Letter I), and any other adjustments the fitter deemed necessary. The fitter determined reach could also be found using a fit cycle or adjustable stem depending on the fitter's preference. The fitter determined postural reach was measured based on predetermined and defined anatomical and mechanical points.

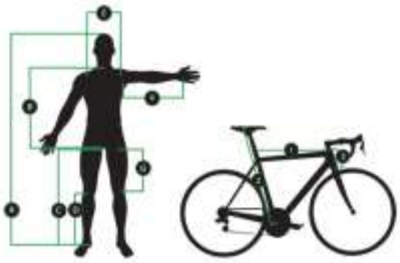

Figure 1. Anthropometric and bicycle measures: A. Height, B. Trunk length, C. Lower extremity length, D. Leg length, E. Shoulder width, F. Upper extremity length, G. Thigh length, 1. Reach, 2. Saddle height, 3. Head tube length.

V. DATA ANALYSIS AND RESULTS

A. *Analysis*

The physical therapist who performed the bicycle fitting coded and recorded the data on an Excel file. The data was then entered into version 25 of SPSS. Upon receiving the data from the treating therapist, a Spearman's correlation was then performed using an a priori alpha of 0.05 for a one-tailed test looking at the relationship between the fitter determined reach and upper extremity and trunk length. The a priori alpha of 0.05 was selected as it is considered the minimum standard for hypothesis testing. The strength of the correlation was determined using the following guidelines: 0 to 0. 25 little to no correlation; 0.25 to 0.5 fair correlation; 0.5 to 0.75 a moderate to good correlation; above 0.75 good to excellent correlation.

Once a moderate correlation was determined, a linear regression was performed to examine if an equation could be found that could describe and predict the relationship between upper extremity length, trunk length, and the postural reach. The normalcy of the data was checked by examining skewness and kurtosis. Also considered was which of the variables, upper extremity and trunk length, was needed to predict the postural reach measure.

B. *Results*

RQ1: Is there a moderate to moderate to strong correlation between the reach determined during bicycle fitting and the anthropometric measures of upper extremity length and trunk length?

The first research question asked if there was a moderate to strong correlation between the reach determined during bicycle fitting and the anthropometric measures of upper extremity length and trunk length. It was hypothesized (**H_{01}**) that there was no relationship between the reach determined by the traditional method and anthropometric measures. When a Pearson Product correlation was performed (see Table 1) with the data gathered, the results indicated a moderate correlation, $r(9) = 0.663$, $p < .05$, between upper extremity length and the reach determined by the bicycle fitter. This correlation coefficient resulted in an r^2-value of 0.44, also known as the effect size and explained variance. This value was considered a medium effect size, statistically. The correlation between trunk length and reach determined by the bicycle fitter had a fair correlation, $r(9)= 0.296$, $p < .05$, and an r^2-value of 0.09. Below 0.10 is considered a small effect size.

Table 1. Pearson's Product Correlation Between Reach and Upper Extremity or Trunk

	Correlation to Reach	
	Upper Extremity	Trunk
Pearson	0.663[a]	0.296
Significant (1-tail)	**0.013**	**0.188**

RQ2: If a moderate to strong correlation does exist between the anthropometric measures and the reach, can a regression formula be determined that accurately describes this relationship?

The second research question examined whether a linear regression formula could be determined that accurately describes the relationship between anthropometric measures and reach if a moderate to strong correlation existed. For this question, it was hypothesized (**H_{02}**) that postural reach could not be determined via an equation. As can be seen in Table 2, Model 1, the correlation was still significant for the regression. The results of the linear regression (Model 1) was significant and demonstrate that the length of the upper extremity and trunk can be seen to help predict the reach, $F(2, 10) = 5.49$ (Table 3). A test of skewness and kurtosis show that both are between -2 and 2, which demonstrates normality within the data (Table 4). The resulting equation that predicts the reach measure based on the length of the upper extremity and trunk is the following: *Reach = 27.28 + UE(1.2) + Trunk(-.45) + 3.30* (Table 5 and Table 6), where reach stands for the distance between the saddle and the handlebars, UE stands for the length of the upper extremity, and trunk for trunk length.

Table 2. Model Summary for Dependent Variable: Reach

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate
1	0.76[a]	0.58	0.47	3.30
2	**0.66[b]**	**0.44**	**0.38**	**3.59**

[a]Predictors: Constant, Trunk, Upper Extremity
[b]Predictors: Constant, Upper Extremity

Table 3. ANOVA for Dependent Variable: Reach

Model		Sum of Squares	df	Mean Squares	F	Significant
1	Regression	119.51	2	59.75	5.49	0.032[a]
	Residual	87.04	8	10.88		
	Total	206.55	10			
2	Regression	90.81	1	90.81	7.06	0.026[b]
	Residual	115.74	9	12.86		
	Total	**206.55**	**8**			

[a]Predictors: Constant, Trunk, Upper Extremity
[b]Predictors: Constant, Upper Extremity

Table 4. ANOVA for Dependent Variable: Reach

Model		Sum of Squares	df	Mean Squares	F	Significant
1	Regression	119.51	2	59.75	5.49	0.032[a]
	Residual	87.04	8	10.88		
	Total	206.55	10			
2	Regression	90.81	1	90.81	7.06	0.026[b]
	Residual	115.74	9	12.86		
	Total	**206.55**	**8**			

[a]Predictors: Constant, Trunk, Upper Extremity
[b]Predictors: Constant, Upper Extremity

Table 5. Descriptive Statistics for Regression

	n	**Mean**	**Skewness**		**Kurtosis**	
	Statistics	Statistics	Statistics	Std. Error	Statistics	Std. Error
Upper Extremity	11	66.83	-0.17	0.66	-0.57	1.28
Trunk	11	54.43	0.67	0.66	-0.38	1.28
Valid N	**11**					

Table 6. Coefficient for Dependent Variable: Reach

Model		**Unstandardized Cfs**		**Sdz Cfs**			**Correlations**		
		B	SE	Beta	t	Sig	Zero	Partial	Part
1	Constant	27.28	17.12		1.59	0.15			
	UE	1.20	0.39	1.15	3.05	0.02	0.66	0.73	0.70
	Trunk	-0.46	0.28	-0.61	-1.62	0.14	0.30	-0.50	-0.37
2	Constant	36.34	17.53		2.09	0.07			
	UE	**0.70**	**0.26**	**0.66**	**2.66**	**0.03**	**.66**	**.66**	**.66**

Note. Cfs = coefficients; Sdz Cfs = standardized coefficients; SE = standard error; Zero = zero-order.

Table 7. Residuals Statistics for Depedent Variable—Reach

	Minimum	Maximum	Mean	Std Deviation	n
Predicted Value	77.83	88.13	83.14	3.01	11
Residual	-7.65	3.83	0.0	3.40	11
Std. Predictided Value	-1.76	1.66	0.0	1.0	11
Std. Residual	**-2.13**	**1.07**	**0.0**	**0.95**	**11**

[a]Predictors: Constant, Trunk, Upper Extremity

An examination of the coefficients of the regression via step-wise regression (see Table 6) indicated that the trunk measure was not significant. Because of this, it would be statistically justifiable to simplify the regression by removing the trunk measure. The removal of the trunk length measure results in a regression that is still significant and can predict the postural reach measure based solely on the upper extremity measure, $F(1, 9) = 7.06$ (see Table 4). This results in a regression equation: $Reach = 33.34 + UE(.70) + 3.4$.

Evaluation of the Findings

This study found a moderate correlation between the length of the upper extremity and the reach. This is similar to the findings of Grainger, Dodson, and Korff[11], though they also found a correlation with trunk length, which this study failed to find. It should be noted that the authors were examining children[11]. The only other study that examined anthropometrics of the upper extremity length was conducted by Baino[21], who did not determine that a correlation existed.

When examining the findings of this study against the mathematics of a triangle, it is somewhat surprising that a correlation did not exist. It was expected that because of the nature of a triangle, a strong correlation would be found. This is possibly because in this study, the upper extremity and trunk were considered a rigid segment while in reality, they are not. This is particularly true for the trunk length that has multiple joints within the thoracic spine, lumbar spine, and proximal femur.

The effect size, or r^2 , found with the correlation is also important to note. The effect size was between medium and large, with $r(9) = .663$, $p < .05$ and the $r^2 = .439$. This is noteworthy because of the small sample size that was used. This study was only a pilot study and used a small number of subjects or data points. While taking the trunk, upper extremity, and reach measurements is considered a normal part of the fitting process many physical therapists do not include them when time becomes an issue. This fact resulted in difficulties gathering data.

A linear regression was then completed and found to be significant both with and without the trunk length measure. However, the trunk length measure was not significant and did not add strength to the model. Therefore, justifying the removal of this factor and still having a regression that is significant and able to predict the reach measure is appropriate. It is possible to determine a regression equation based on the length of the upper extremity that can be used to determine the reach of this data set.

VI. CONCLUSIONS

This quantitative retrospective correlational study had two specific aims: 1) to answer if there was a moderate to strong correlation between the reach determined during bicycle fitting and the anthropometric measures of upper extremity length and trunk length, and 2) to determine, if a strong correlation did exist between the anthropometric measures and the reach, whether a regression formula could be determined that accurately describes this relationship.

It was hypothesized that there would not be a correlation between the length of a cyclist's upper extremity and trunk lengths and the reach determined by the fitter. When examining the findings, the hypothesis was partially rejected. This study found a correlation between the upper extremity and the reach determined by the fitter; however, there was no correlation between the trunk and the reach.

These findings are somewhat surprising when you consider that the study's grounding theory was the mathematics that can be used to describe a triangle. This may mean that the relationship is not a true triangle, or that the measurements taken by the fitters were not consistent enough between fitters to describe the relationship between the segments of the upper extremity and trunk lengths and the postural reach. While the fitters were all generally measuring the same segments, because this was a retrospective study the method for making the measurements was never operationalized.

Each fitter may have been using slightly different methods. The measurement of the upper extremity is much more straight forward as this segment is made up of only two bony segments: the humerus and bones of the forearm. This is in contrast to the trunk, which is made up of multiple smaller segments of the spine that are thereby more influenced by the change of position between standing and weight-bearing on the upper extremities in the riding position. In normal standing position on the ground a cyclist is able to slouch and increase the thoracic and lumbar curves. When on the bicycle, the upper extremities are now bearing weight and there is a possible decrease in both the thoracic and lumbar curves, which would lead to a lengthening of the trunk. A series of studies found that not only the thoracic and lumbar curves change between standing and when the hands are placed on the handlebars, but that the experience level of the cyclist also affects these changes[2,5,7,9,13,15,20].

While there was a fair correlation between the trunk length and reach, there was a moderate correlation between the reach and upper extremity measures. These correlations do point to further need to explore the relationship of the anthropometric measures, trunk and upper extremity length, and the postural reach with a larger sample. The assumptions drawn from this relationship are limited as the correlation design itself has inherent issues as correlation does not prove causation.

The second hypothesis asked if it would be possible to develop a regression formula that would help describe the postural reach distance by using the anthropometric measures when a correlation existed. As the results showed, it was possible to determine a statistically significant equation to describe the significant correlated relationship between the upper extremity and trunk length and the postural reach.

An issue with completing the linear regression was, again, the low number of data points. There has been a continued discussion in the literature about the number of data points required per variable entered, resulting in a several "rules-of-thumb," with no consensus as of yet. It has been suggested that thirty subjects are needed for each predictor when completing a multiple regression. Others have stated up to one hundred and four subjects plus one subject for every predictor explored. A more recent study suggested only two subjects per predictor being investigated[22]. Because this was a pilot study, the number of data points used does not meet at least two of these suggestions. While this may cause one to question the findings of this study, the goal was never to find an equation that would exactly define the postural reach of the individual but rather to find a starting point for the fitter to work.

While the regression completed with the trunk length measure was significant, the trunk measure was seen not to be significant or add meaningfully to the results. Due to this fact, the removal of this factor was justified. The resulting equation was still significant and was able to predict the postural reach measure based on the upper extremity length.

The only other study that has examined the relationship between the anthropometric measures of upper extremity and the trunk and postural reach also found there to be a correlation for both the upper extremity and the trunk length measures[11]. The authors were also able to develop a regression equation to describe the reach component in the fitting process[11]. As previously noted, the study was completed using children whose anthropometric measures relationships do differ with stages of maturation.

This study does demonstrate the general lack of scientific knowledge around bicycle fitting. Further studies still need to work towards connecting the changes made during bicycle fitting and the prevention of repetitive stress injuries. While a significant hurdle is the lack of the technology needed to measure many of the areas of interest, it is paramount that we continue to push forward on these questions. Until researchers understand the connection between bicycle fitting and injury prevention, the process will continue to be subjective and effected by opinion.

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