In-Situ Visualization of Pedaling Forces on Cycling Training Videos

Oral Kaplan*, Goshiro Yamamoto†, Yasuhide Yoshitake‡,
Takafumi Taketomi*, Christian Sandor* and Hirokazu Kato*
*Nara Institute of Science and Technology, Japan Email: {oral.kaplan.nv4, takafumi-t, sandor, kato}@is.naist.jp
†Kyoto University Hospital, Japan Email: goshiro@kuhp.kyoto-u.ac.jp
‡National Institute of Fitness and Sports in Kanoya, Japan Email: y-yoshi@nifs-k.ac.jp

***Abstract*—Over the last decades, visual representations of data has been a commonly used medium to bolster human cognition in performance evaluation of professional athletes. However, the current approaches to these visualizations still build upon the paper based principles of initial designs with solid backgrounds. Due to this situation, same visualizations usually fail to provide explicit information about the physical characteristics of the scenario that the data was captured, such as the form of athletes.**

In this work, we present a data visualization method which combines visual representations of cyclist's pedaling with correlated frames of indoor training videos. We designed a prototype system which allows us to superimpose various pedaling visualizations onto simultaneously captured training videos of cyclists (Figure 1). The results of user studies we conducted with twelve professional cyclists confirmed their interest in new possibilities emerging from intuitive data visualizations. We also received valuable feedback about the feasible benefits of our approach over traditional approaches, such as reduced cognitive overload in understanding visualizations. We conclude by discussing the future implementations and application areas of our approach and further need of adjusting it to distinct training scenarios.

I. Introduction

Visual representations of data employ numerous abstract shapes to utilize distinct properties of our visual system[1][2]. These visualizations can frequently be seen all around us; on newspapers, TV news or simply internet. A line chart showing the change in inflation over the years, a bar chart displaying the election results or a pie chart representing the answers given to a survey are all a part of these visualizations. Although the current popularity level of these methods can mostly be associated with the works of Bertin[3], Tukey[4] and Tufte[5], in fact, the same visualizations were developed a long time ago. In 18th century, Playfair invented line, area, and bar charts to represent changes happening in economical data through time[6]. In 1801, he also invented the pie chart and circle graph to emphasize part-whole relationships, such as the proportions of land that the Turkish Empire had in Asia, Africa and Europe before 1789[6].

It has been more than two centuries and we are still utilizing the same visualization style defined by Playfair. The immense power of his approach can be understood by just looking at this fact alone. Yet, we believe a few aspects of it still can be improved with the help of current level of technology. Computer systems started to move away from imitating textual paper documents with Sutherland's Sketchpad[7] in 1963, but when it comes to visual representations of data, they are still revolving around paper based approaches. Sports training is also an area where the same visualization approach is being used extensively.

Athletic performance depends on a great number of variables. Evaluating the data related to all these variables plays a significant role in every professional athlete's training. On the other hand, the vast amount of data captured in textual or numerical formats make information comprehension substantially difficult. Due to this situation, professional sports communities became dependent on information visualization techniques over the past years[8].

Professional cycling is also a sport where a vast amount of sensors are used for capturing various types of data about cyclist's training. Among all, the data about cyclist's pedaling still remains to be the most important factor in determining performance[9][10][11]. Captured data is most commonly visualized in the form of time series, histograms or scatter plots (Figure 2). Although these visualizations give a nice overview about one's pedaling performance over a long period of time, they usually fail to promote spatial reasoning and provide explicit information on physical characteristics of cyclist's training.

In this work, we introduce a multivariate visualization approach to be used for cycling training. We combine different visualizations with video support to promote causality between one's form and pedaling by utilizing meaningful background images. In order to realize this, we developed a prototype system which allows us to superimpose numerous pedaling visualizations onto simultaneously captured training videos of cyclists. In this paper, we describe our vision and the properties of the visualizations we superimpose onto cycling training videos. We also explain the studies we did with twelve professional cyclists by using our system. The results of interviews showed possible benefits in reducing cognitive overload in understanding the visualizations. Additionally, couple of additional design principles that have to be taken into consideration apart from common visualization methods were also identified. We conclude this paper by discussing the future of our approach and the new possibilities it might bring when compared to traditional visualization methods.

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(a) No background (b) RGB video frames (c) Monochromatic video frames

Fig. 1: A vector based data visualization to represent pedaling forces that employs a solid background (a) and the same visualization superimposed onto RGB (b) & monochromatic (c) frames taken from an indoor cycling training video.

II. Related Work

A. Situated Visualizations

The idea of having a visualization with a meaningful background is not a new approach from information visualization point of view, but to our knowledge it has never been applied to cycling or cycling training. White introduced the term *Situated Visualization* for referring to a visualization which is related to its environment[12]. SiteLens is a system that visualizes virtual data in the context of its physical site to support site visits of professional urban planners, designers and architects[13]. With SiteLens White et al. aimed to support professionals in sense making, pattern finding and insight discovery about a physical site and its characteristics through emphasizing a data visualization's relationship to its environment. ClayVision is an urban navigation system developed by Takeuchi and Perlin which addresses the problems arising from the information bubble trend in vision based Augmented Reality(AR) applications[14]. This visualization scheme attracts a significant amount of user's attention which eventually reduces the attention given to other details related to the physical world. Instead of pasting information bubbles, they employ free-form transformations on real world elements to convey related information. Kalkofen et al. introduced interactive visualizations to emphasize existing spatial relationships between virtual and real objects in AR applications[15]. They explored the effects of focus and context on user's perception when information is presented in its real environment where the scene's clutter density is usually high. Zollmann et al. designed an interface which augments user's view with relevant information to support flight management of micro aerial vehicles[16]. With their approach, they aimed to provide spatial information about the environment and support the cognitive abilities of users.

B. Pre-attentive Features

When we visualize data with charts, we simply employ meaningful abstract representations. Depending on the context of data, these abstractions might include lines for representing change over time, bars with a common baseline for value comparisons or dots for representing the distribution. The effectiveness of these visualizations is mostly dependent on a set of rules defined as preattentive features. Healey defines preattentive processing as a limited set of low-level visual properties that are detected very rapidly and accurately by our visual system system[17]. Generally, a preattentive target can usually be detected in less than 250 milliseconds. In our visualizations, we mainly try to make use of length, size and hue to convey information as fast as possible to cyclist's about their pedaling performance.

C. Pedaling in Cycling

Although pedaling might seem like a straightforward circular action, it is not a simple movement as one might think. Complex structure and the lack of a ground truth in pedaling usually causes unexpected problems and produces unwanted outcomes when it comes to cycling specific visualizations. Designing a visualization specific to cycling training unmistakably requires a deep understanding about pedaling dynamics.

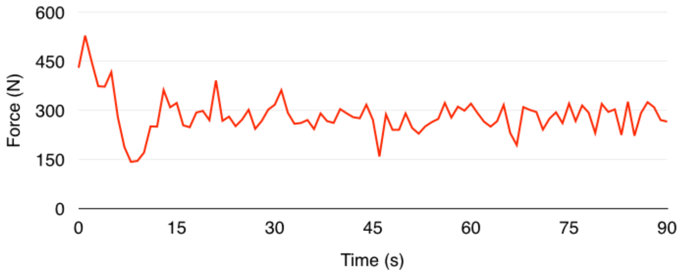
Dorel and Hug gave an overview of pedaling technique in cycling by using electromyography(EMG)[11]. They mainly described the patterns of the lower limb muscle activation and the constraints that effect these patterns such as power output, pedaling rate, body position and fatigue. Results showed significant amount of differences in muscle recruitment patterns and pedaling techniques of professional road cyclists.

Dorel et al. investigated the contribution of each functional sector of pedaling on the total force produced over a complete pedaling cycle, including down-stroke, up-stroke and transition phases[10]. A large positive contribution to total force production during the down-stroke phase and a slight negative contribution during the upstroke phase were commonly observed between participants. Total and effective forces produced during a complete pedal revolution were measured at different pedaling rates and difference between were the greatest especially at high pedaling rates.

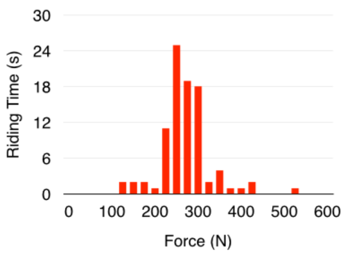
III. System Design

A. Scenario

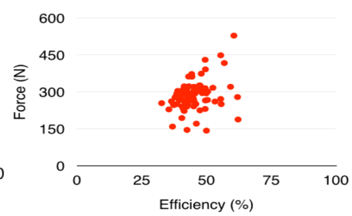
Training in professional cycling commonly includes both indoor and outdoor training. As the name implies, outdoor



(a) Line chart



(b) Histogram



(c) Scatter plot

Fig. 2: Commonly used visualizations in sports training for assessing and evaluating athletic performance

training includes the training done by riding outside with a certain training schedule or goal. Whereas, indoor training in cycling might be understood in two different ways; one is the muscle training that can be done without any cycling equipment and other one is the indoor cycling training done with rollers or bicycle resistance trainers.

While designing the system the main scenario that we focused covered an indoor cycling training with a bicycle resistance trainer. These trainers allow cyclists to train by using their own bicycles while it remains stationary. Simply, they convert a normal bicycle into a cycling ergo-meter that exemplary ones can mostly be found in gyms. Main purpose of use includes warming up before a race, training indoors during bad weather conditions or simply strength training. Training sessions with these type of trainers can also be used to evaluate the effects of current form on pedaling forces.

During the experiments, we expect cyclists to undergo a certain training session with a specific goal in mind. In more detail, cyclists are expected to see the changes happening in their form throughout the training session and evaluate the effects of these changes on their pedaling forces.

B. Components

The experimental setup we used included a power meter equipped bicycle mounted to a bicycle resistance trainer. The power meter we have chosen for this research was Pioneer Pedaling Monitor System. This system allows us to extract tangential and radial force components in every 30° of one full crank rotation. The pedaling monitor system was installed on a Dura Ace 9000 FC-9000 with 52-36T combination and 172.5 mm crank arm length. The rear cassette was a Dura Ace CS-7900 with 11-28T combination. The resistance trainer we used was a Tacx Booster T2500.

Fig. 3: Triangles representing the amount of torque generation

The training videos were captured by using a Logicool HD Pro Webcam C920r. An Optitrack Trio V120 were used to track the passive reflective marker attached pedal in video frames and to extract data about pedaling trajectory and measurement points. Both cameras were calibrated prior to usage by using a calibration board with a 7x10 chessboard pattern and three passive reflective markers.

C. Force Visualizations

While designing the visualizations used with training videos, we focused on three different aspects of pedaling. These were resultant force vectors, torque generation and the directional deviation between torque and force vectors.

We implemented a vector based visualization based on the one used by the power meter system itself to represent direction and magnitude of resultant forces. This visualization allows cyclists to interpret the information about the forces measured at twelve measurement points through length and orientation. Hue was used to explicitly provide information about produced force's effect on crank rotation. Such as, a blue vector means positive contribution to rotation whereas a red vector means negative contribution. A white vector represents force with no contribution at all.

For visualizing the torque generation, we employed a vector and a triangle based approach (Figure 3). Similar to vector visualization, color was again used to explicitly provide information about produced force's effect on crank rotation.

Finally, for visualizing the directional deviation between torque and force vectors, we again used two methods including a vector and a triangle based approach. We used blue to represent torque and yellow to represent force with positive contribution to rotation. In terms of negative contribution to rotation, we only visualized forces while omitting the torque information for increased visual simplicity.

IV. User Study

A. Experiments with Professionals

We evaluated our approach with a user study where ten male and two female professional cyclists participated. Participants were chosen from various cycling disciplines including eight road cyclists, three track cyclists and one time trialist. Average age was 20 with a minimum of 19 and a maximum of 23 years old. Their professional cycling experience was an average of 6 (Min 1, Max 10) years. The professional backgrounds of cyclists included first place in All-Japan Inter-College 3 km Cycling Championship, first place in All-Japan Inter-College Team Sprint, victory in All- Japan Road Race Championship Under 23 and several victories in both national and international time trial events.

The test environment were the same between all participants except for the saddle height. We modified saddle height according to each participant's preferred height or inseam length. The test procedure we followed employed three different intervals. During the first interval, male cyclists were expected to generate power equal to seven times of their body weights in watts for one minute. During the second interval, participants were expected generate power equal to ten times of their body weights in watts for thirty seconds. The final part employed a maximal effort for a total of ten seconds. Multipliers were modified for female participants as six and eight times of their body weight. The maximal effort interval remained the same for female cyclists. All participants took an active recovery break of five minutes between each interval by slowly pedaling with a low gear low resistance combination. We encouraged participants to keep a steady cadence of 90 rpm during the first and second intervals. Since final interval was a maximal effort, we did not specify any cadence value. We used a metronome to aid participants in keeping a steady cadence value. During each trial, we kept the front gear constant; chain was on outer chain ring. We started the timer for each interval after the cyclist reached the desired cadence of 90 rpm. The rear gear and trainer's resistance level was controlled and determined according to the values represented in Table I.

FIRST INTERVAL

Body Weight(kg)	Power(W)	Rear Gear	Resistance Level
40	280	2/10	7/10
50	350	4/10	7/10
60	420	5/10	7/10
65	455	7/10	7/10
70	490	8/10	7/10
75	525	7/10	8/10
80	560	7/10	8/10
85	595	8/10	8/10

SECOND INTERVAL

Body Weight(kg)	Power(W)	Rear Gear	Resistance Level
40	400	6/10	8/10
50	500	6/10	8/10
60	600	8/10	8/10
65	650	9/10	8/10
70	700	10/10	8/10
75	750	10/10	8/10
80	800	10/10	8/10
85	850	10/10	8/10

TABLE I: Experiment settings we used with male participants

B. Interviews with Professionals

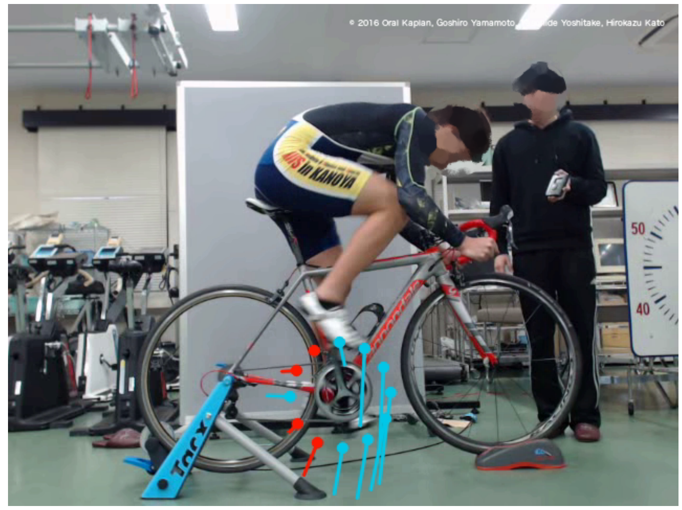
Following each experiment, we had a short interview in the form of free talks with the participant for about 15 minutes. We recorded the personal data of participant during the first part of the interview. Such data included age, weight, gender, profession, specialization, experience and professional background. During the second part, we asked specific questions prepared to collect information about pedaling technique and video usage in cycling training. Finally, we allowed participants to express their objective thoughts, comments and suggestions about the concept of our research.

The biggest part that we find useful in the interviews was unmistakably the comments that we received from each participant. Almost all participants had experience with using videos or mirrors to assist their training needs. The most common purpose of using these two mediums was to check their own form during training. The points that they mostly focused in their form was the angle of their ankle, fore-aft saddle position and aerodynamic posture. One female participant also expressed her usage of videos for checking cleat positioning. When we asked them about their objective thoughts on using videos with pedaling force visualizations, all participants had a positive approach towards it. By using a combination of videos and charts, it was obvious to them that they can easily get information about both their forms and their pedaling styles at the same time. One participant strongly believed in the possibilities of new training methods that can be achieved with this kind of visualizations, such as finding a balance between aerodynamic posture on the bicycle and the resultant pedaling.

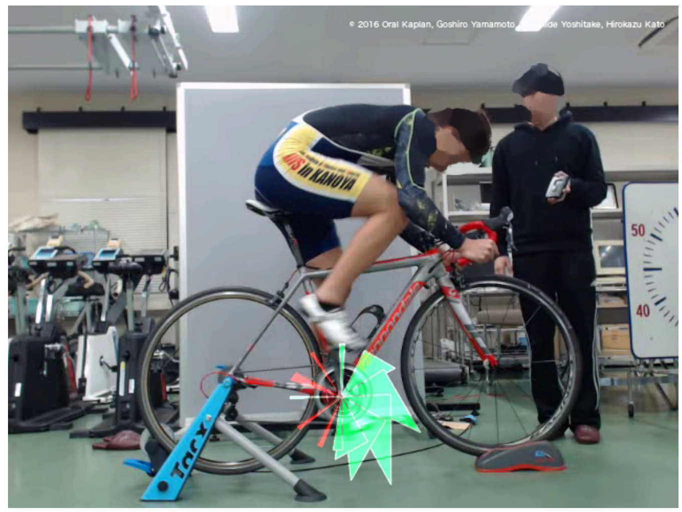
An unexpected result that we achieved from the interviews was about the force visualization part of our approach. From our perspective, vectors were expected to be the most suitable method of visualizing information about force magnitude and direction. Yet, most of the participants also favored the area visualizations in addition to the vector visualizations. When we asked them about the reasons behind their interest, the most common answer was the increased visibility of the chart due to wider area being used to draw it. A particular aspect that almost all participants agreed was given the right design, this increased visibility would make the visualization easy to understand after or during the training. Due to physical and mental fatigue placed upon their bodies during and after training, a visualization that clearly appears to the eye was highly favored by the participants. On the contrary, when we showed the same visualizations to unprofessional cyclists belonging to information science field, same visualizations had no value over the ones using utilizing vectors. It is clear that the user profile and the properties of the sport are extremely important factors that need to be taken into account while designing sport specific visualizations.

All participants were positive about comparing their current performance with their past performances. By doing so, they were expecting to see the increase or decrease in their pedaling performance with respect to their physical form on the bicycle. A point mentioned by the most of participants was to use our approach to compare their pedaling styles while their form is relatively bad and good to see if any significant differences exist in their pedaling performance. The answers to the question about comparing one's own performance with somebody else were mostly negative. Main reason behind this result was mostly due to the certain differences in body structure and muscle recruitment patterns between each individual. Although two participants were positive about this kind of comparison, they only wanted to make it with people whose body structures are close to theirs. Yet, they did not fully believed in this approach and its potential since most of them already had a clear understanding about their own pedaling style and believed it would be substantially difficult to modify according to another cyclist's style.

Finally, a common suggestion from participants was towards the making of a real-time application where our approach can be used during outdoor training. Their main desire was to be able compare their performance in a scenario which is the same or as close as to real world scenarios such as races. For example, since the bicycle and the resistance trainer were fixed in place, using one's own body weight was not an option. Participants expected to see significant differences in their pedaling performances between indoor and outdoor training scenarios. Although, five participants also mentioned that they do not explicitly place their focus nor on their pedaling neither on their forms during outdoor training. This was mostly due to the possible dangers it might pose if they are not fully aware of their surroundings. Participants also believed in the value of an indoor training scenario which can replicate the outside conditions, which remains to be an important milestone in our future work calendar.



(a) Track cyclist force vectors



(b) Track cyclist torque triangles

Fig. 4: Occlusion in pedaling visualizations of one track cyclist

V. Discussion

User studies with professionals clearly revealed that the videos are not the most commonly used medium in cycling due to the limitation of scenarios where they can be truly useful. Although all participants had an experience with video usage to capture and evaluate their form, some of them used videos as infrequently as twice a year. When presented with our approach, all participants were positive about using it for their personal training, but only if provided in a way which is easy to setup and use. We believe the main reason behind that interest was the direct relationship that can be formed effortlessly between cyclist's form and its effects on pedaling. As mentioned before, current approaches to performance evaluation in cycling mainly focus on the results rather than causes. There is no denial that the current methods are highly useful. The point that we are interested in as researchers is to overcome the strict boundaries defined to separate those methods from each other. Since videos can only provide information that can be seen with naked eye made videos suitable for evaluating cyclist's form or position on the bike. The same can also be said for pedaling visualizations where the things that cannot be perceived with naked eye are made available. We believe better training regimes can be established with intelligent combinations of distinct visualization methods. We think if we would like to overcome the difficulties caused by the complicated nature of pedaling, methods similar to ours can be highly useful in analyzing and evaluating performance in cycling.

When asked to choose a chart for visualizing pedaling forces on videos, the answers pointed to both area and vector visualizations. Area visualizations were mostly preferred due to increased amount of screen space used while drawing. This also made them easier to perceive when superimposed on videos and eased required effort while making rough evaluations. All participants mentioned the importance of this property since physical and mental stress placed upon their bodies due to training also effected their cognitive abilities. Participants expressed that the comprehension of information might require less effort with area visualizations. However, visualizing more than one data as areas was also defined as impractical since it might simultaneously increase the complexity. Vector visualizations were mostly seen useful due to participants familiarity with the method. We believe the effects of this phenomenon named as mere-exposure principle requires a better understanding

Vectors showed great qualities in extracting directional information about cyclist's pedaling. Yet, the reduced information integrity and visual simplicity also made it difficult for cyclists to extract a general pattern out of these visualizations. In this context, area visualizations representing torque generation received more attention. Participant's torque generation pattern was roughly identified during each interval. However, this visualization had occlusion problems when used with professional cyclists (Figure 4).

As a result, we believe there are three important aspects that a pedaling visualization superimposed onto correlated background images should satisfy; visual simplicity, information integrity and occlusion free (Figure 5). A quantitative analysis on visualizations satisfying these points might reveal much needed additional information for our future designs.

Fig. 5: Monochromatic video frames combined with independent visualizations of force direction and force magnitude

VI. Conclusion

In this paper, we introduced a data visualization method that combines cycling training videos with visual representations of cyclist's pedaling. We employed various pedaling visualizations to better understand the important properties and significant aspects of our approach. We tested our ideas with professional cyclists and received positive feedback about the feasible benefits of our approach over common visualization methods used in cycling training. The most frequently expressed concern by the participants was about the effects of physical and mental fatigue on understanding and evaluating the visualizations. We believe three properties might play a significant role in future visualization designs; visual simplicity, visualization integrity and occlusion free.

In the future, a comparison of preattentive vision features during sports training might reveal highly important information to be used while designing sports specific visualizations. A quantitative analysis on benefits of our approach over traditional ones is also marked as an important milestone in our calendar. Additionally, carrying our experimental scenario towards outdoor usage might also open up new possibilities in cycling training. Finally, in this work we have only taken side views into consideration. The design requirements which might emerge from employing different viewpoints is also a topic that attracts our attention in the future.

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References

[1] B. Shneiderman, "The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations," *Proceedings of the IEEE Symposium on Visual Languages*, pp. 336–343, 1996.

[2] B. Shneiderman, "Extreme Visualization: Squeezing A Billion Records Into A Million Pixels," *Proceedings of the ACM SIGMOD International Conference on Management of Data*, pp. 3–12, 2008.

[3] J. Bertin, *Semiology of Graphics: Diagrams, Networks, Maps*, 1983.

[4] J. W. Tukey, *Exploratory Data Analysis*, 1977.

[5] E. R. Tufte, *The Visual Display of Quantitative Information*, 1983.

[6] S. Few, *Now You See It: Simple Visualization Techniques for Quantitative Analysis*, 2009.

[7] I. E. Sutherland, "Sketchpad: A Man-machine Graphical Communication System," *Proceedings of the AFIPS Spring Joint Computer Conference*, pp. 329–346, 1963.

[8] A. Cox and J. Stasko, "SportVis: Discovering Meaning in Sports Statistics Through Information Visualization," *Conference Compendium of IEEE Visualization, IEEE Symposium on Information Visualization and IEEE Symposium on Visual Analytics Science and Technology*, pp. 114–115, 2006.

[9] W. M. Bertucci, A. Arfaoui, and G. Polidori, "Analysis of the Pedaling Biomechanics of Master's Cyclists: A Preliminary Study," *Journal of Science and Cycling*, vol. 1, no. 2, pp. 42–46, 2012.

[10] S. Dorel, A. Couturier, J. R. Lacour, H. Vandewalle, C. Hautier, and F. Hug, "Force-Velocity Relationship in Cycling Revisited: Benefit of Two-Dimensional Pedal Forces Analysis," *Medicine and Science in Sports and Exercise*, vol. 42, no. 6, pp. 1174–1183, 2010.

[11] F. Hug and S. Dorel, "Electromyographic Analysis of Pedaling: A Review," *Journal of Electromyography and Kinesiology*, vol. 19, no. 2, pp. 182–198, 2009.

[12] S. White, "Interaction and Presentation Techniques for Situated Visualization," Ph.D. dissertation, Columbia University, 2008.

[13] S. White and S. Feiner, "SiteLens: Situated Visualization Techniques for Urban Site Visits," *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems*, pp. 1117–1120, 2009.

[14] Y. Takeuchi and K. Perlin, "ClayVision: The (Elastic) Image of the City," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 2411–2420, 2012.

[15] D. Kalkofen, E. Mendez, and D. Schmalstieg, "Comprehensible Visualization for Augmented Reality," *IEEE Transactions on Visualization and Computer Graphics*, vol. 15, no. 2, pp. 193–204, 2009.

[16] S. Zollmann, C. Hoppe, T. Langlotz, and G. Reitmayr, "FlyAR: Augmented Reality Supported Micro Aerial Vehicle Navigation," *IEEE Transactions on Visualization and Computer Graphics*, vol. 20, no. 4, pp. 560–568, 2014.

[17] C. G. Healey and J. T. Enns, "Attention and Visual Perception in Visualization and Computer Graphics," *IEEE Transactions on Visualization and Computer Graphics*, vol. 18, no. 7, pp. 1170–1188, 2012.