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Effectiveness of Integral Kinesiology Feedback for Fitness-based Games

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***Abstract*—Existing physical fitness systems are often based on kinesiology (physical kinematics) which considers distance and its derivatives which form an ordered list: distance, velocity, acceleration, jerk, jounce, etc.. In this paper, we examine the efficacy of using integral kinematics to evaluate performance of exercises that combine strength and dexterity. Integral kinematics is based on distance and its time integrals (absement, absity, abseleration, etc.). We also include a game design framework to further motivate integral kinesiology as a new form of fitness training and fitness assessment.**

I. Introduction

This paper presents a new framework for the development of fitness as well as for the assessment (evaluation, measurement, etc.) of fitness using new conceptual frameworks based on the time-integrals of displacement. The new framework is called "integral kinesiology". The word "integral" has multiple meanings, e.g. in addition to meaning the reciprocal of derivative, it also derives from the same Latin language root as the word "integrity", and thus integral means "of or pertaining to integrity".

This connects to our broader aim to bring a new form of integrity to three important areas of human endevour:

- Integral Veillance: Surveillance tends toward the veillance of hypocrisy (sensing people while forbidding people form sensing), and the opposite of hypocrisy is integrity, thus we must evolve from a surveillance society to a veillance (sur/sous/meta/veillance) society;
- Integral Intelligence: AI (Artificial Intelligence) involves machine sensing which often happens without humans understanding what's happening around them. In this sense AI is a form of surveillance. Thus we must evolve from surveillance intelligence to veillance (integral) intelligence.
- Integral Kinesiology, the topic of this paper.

A. Background

Physical fitness has traditionally been measured and improved through the use of kinesiology. Kinesiology derives from the Greek words "$\kappa\iota\nu\eta\mu\alpha$" ("kinema") which means "motion" and "$\lambda o\gamma o\varsigma$" ("logos") which means "reason" or "study". Thus kinesiology is the study of motion, and in particular, the application of kinematics to physical fitness. Kinematics itself also derives from the Greek word "$\kappa\iota\nu\eta\mu\alpha$" ("kinema"), and traditionally is the study of distance and its derivatives:

- distance (displacement);
- velocity (speed);
- acceleration;
- jerk;
- jounce; ...

If we look at differentiation as an operator, $(d/dt)^n$ (i.e. as action of the differential operator), we can place distance and its nth derivative on a number line, with $n = 0$ for distance, $n = 1$ for velocity (i.e. 1st derivative), $n = 2$ for accceleration (i.e. 2nd derivative), etc..

Looking at this numberline, we see that we only have half the picture, i.e. only the right side of the numberline. If we consider the entire number line, we will also want to consider distance and its time *integrals*, such as $\int dt = (d/dt)^{-1}$, which acts on distance to give a quantity known as absement [1], [2]. Likewise, for $n = -2$, we have $\int\int dt = (d/dt)^{-2}$ acting on distance to give a quantity known as absity. For $n = -3$ we have abseleration, for $n = -4$, abserk, for $n = -5$, absounce, etc..

Absement first arose in the context of the hydraulophone (underwater pipe organ), and flow-based sensing (hydralics) [1].

Kinematics has traditionally been the study of distance and its derivatives, but we proffer the concept of "Integral Kinesiology" which is the study of distance and its derivatives AND integrals. In this way integral kinesiology gives us a more complete picture.

It is interesting to also note that the word "integrity" comes from the same Latin root as the word "integral": integritas ("wholeness", "soundness", "completeness", "correctness", from "integer" ("whole") [www.etymonline.com/word/integrity].

In this way, *Integral Kinematics* brings completeness and correctness to the otherwise "half truth" of considering only the postive half of the spectrum of derivatives.

Likewise *Integral Kinesiology* brings integrity to physical fitness in new and significant ways.

B. Buzzwire

Let us begin with a well-known game of the prior art, "buzzwire", which comprises a serpentine wire, along which participants attempt to move a conductive loop without touching the loop to the wire. See for example, Kovakos, U.S. Patent 3208747, 1965.

This game requires a steady hand, i.e. a certain degree of dexterity.

The game is digital in the sense that the electric circuit is binary, i.e. either open (zero) or closed (one). In this sense, the penalty for almost, but not quite touching the wire, is zero.

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Mann *et al.*undigitalized this game, by making a virtual undigital buzzwire game in which the serpentine path was drawn abakographically in a virtual space by moving a light bulb through the space to generate a long-exposure light trail, and then attempting to move along the light trail with a virtual ring, while not touching the light trail [3]. Being undigital is the concept of using digital computers to achieve continuous (analog) results. Examples of undigitalization include PWM (Pulse Width Modulation) which uses a binary (digital) output to achieve a continuous voltage, and HDR (High Dynamic Range) imaging, which uses digital cameras to produce undigital images [4].

The Mann *et al.*version of buzzwire provides an undigital game in which the score is in proportion to the reciprocal of the absement along the virtual wire. A first particpant draws a serpentine path with a light bulb in a long-exposure photograph, and then challenges subsequent participants to "ring" the wire, following along the same path. The nearest distance from the path is calculated for each time period, and the integral of this distance (i.e. area under time time-distance curve) is calculated. This integral is the absement, so the goal is to minimize the absement (integrated error in position).

In a physical embodiment of this invention, a proximity sensor senses the distance between the wire and the ring, by way of a capacitance meter, so that it measures how close the ring is to the wire. In this way, rather than a binary continuity tester, the feedback is continuous (analog) rather than binary digital.

Fig. 1 shows an early prototype invented and built by Mann, using refrigeration tubing (easy to bend into nearly any desired shape) for the wire, and an open-ended wrench for the ring. A capacitance meter is used to sense the proximity of the wrench ring to the wire, to obtain a distance estimate which is then integrated to obtain absement.

Fig. 1. Left: Undigital buzzwire game. A serpentine length of wire (copper refrigeration tubing) is connected to one terminal of a capacitance meter (proximity sensor), and the other terminal is connected to an open-ended wrench. Distance between the wrench and the wire is sensed, and the distance from the center of the wrench is calculated. This calculated center-distance is then integrated to obtain absement. Score is based on the reciprocal of the absement. This game tests dexterity. Right: By adding weights, we turn this game into a physical fitness activity that measures and developes "dextrength", i.e. a combined simultaneous exertion of dexterity and strength. The MannFit$^{\text{TM}}$system [5] is a commercialization of this technology in which absement is integral to building combined simultaneous strength and fine-motor control. Bottom: Extreme strength combined with fine-motor control, by adding massive quantities of weight.

C. Deadheading

Another activity that involves integrized fitness is deadheading. Deadheading is the complete obstruction of hydraulic flow to the point of zero flow, at which point the resulting hydraulic head is referred to as the "dead head".

The proper technique for deadheading an upwards-facing hydraulic jet is to approach it from a sufficient height above the jet so as to easily cover the water, and then gradually lower down upon it. For example, a downward-facing palm is placed in the jet, and the hand is lowered until the jet is completely obstructed, but without touching the jet itself until it is completely obstructed (e.g. not bracing the hand against the solid matter from which the jet is made). Proper deadheading technique is illustrated in Fig. 2.

D. "Head Games" for teaching concepts of Hydraulic Head

A series of outdoor research, teaching, and lab events were created at Stanford University (See Fig. 3) to leverage Stanford's "fountain hopping" culture (Fig. 4) toward our idea of a "teach beach" [6]. Nearly every day, Stanford students and professors gather around (and some jump into) Stanford's glorious fountains, such as Tanner fountain. Some of the professors even hold their classes in the fountain. For example, during one of our "Head Games" lectures/labs, another professor was using the fountain for teaching a drama class.

Thus we envision in the future, a more fully equipped "teach beach" that embodies elements of waterpark, spa, research lab, (outdoor) classroom, and "beach culture".

One exhibit/teaching feature we envision in this environment is a waterfall that teaches concepts of hydraulic head, by way of a circular staircase surrounding it, with every step a known height such as 20cm, and a landing every 5 steps, so that there are landings every metre of elevation. Conversely we wish to exhibits head from ground level, as well as head from jet mouth exit, and thus mark the height increasing and decreasing from top-to-bottom as well as from bottom-to-top.

Another feature of our setup is the "teach beach" climbing wall, with water jets, for deadheading while climbing. See Fig. 8.

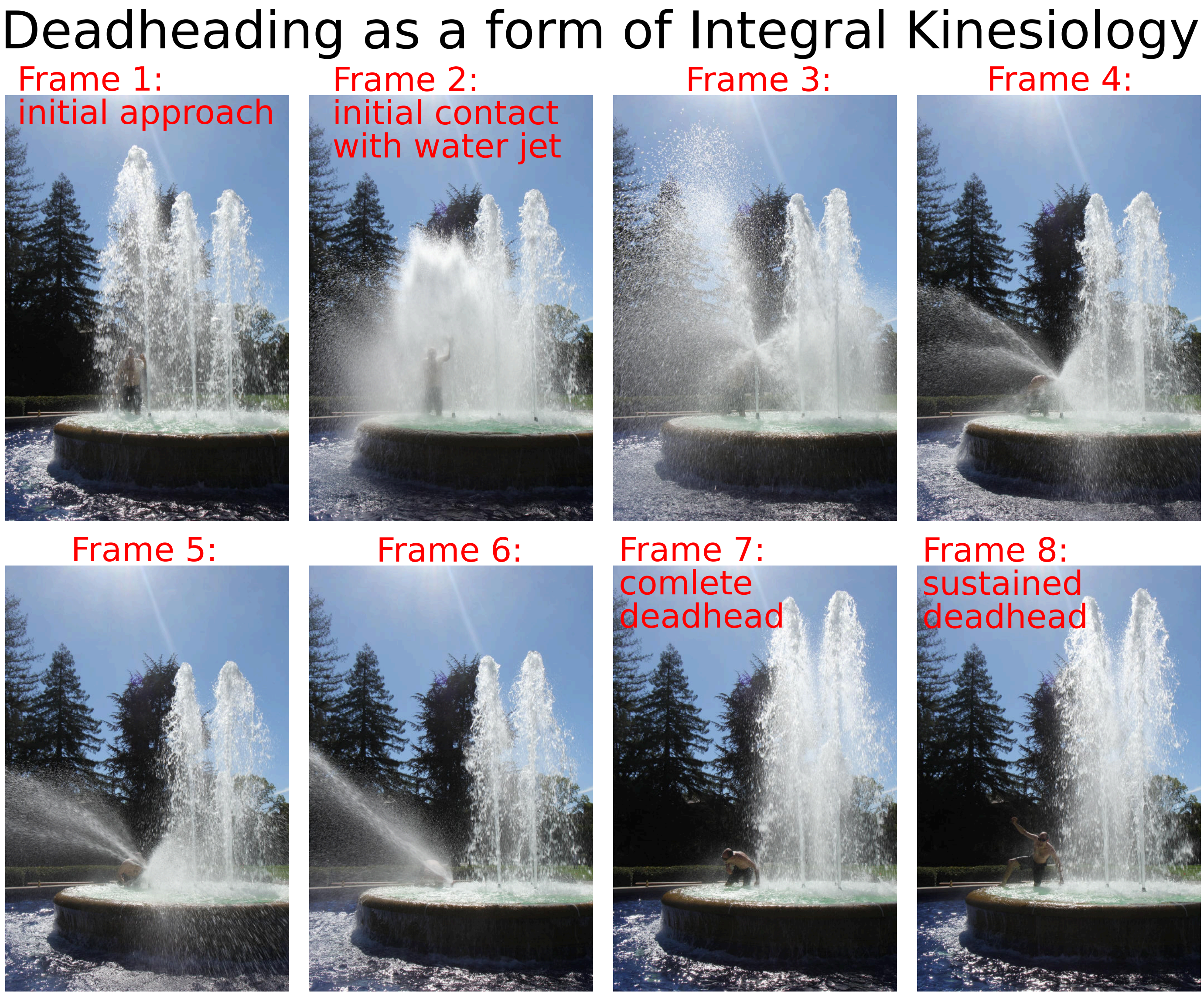

Fig. 2. Demonstration of proper deadheading technique by deadheading the tallest jet of Stanford's Tanner fountain with just one hand. Novice deadheaders begin by deadheading the smallest jet with both hands, and eventually work up to single-handed deadheads on larger jets as a higher degree of physical fitness is attained. Stanford University has a tradition called "fountain hopping" in which students and professors frolic in the fountains. In this sense Stanford is perhaps the world's epicenter of fountain hopping culture. From July 2016 to January 2018, Tanner fountain formed the venue for a series of lectures, experiments, and teachings on principles related to hydraulic head.

E. Motivation for Integral Kinesiology

Inactive lifestyle is a risk factor for many individuals in the 21s century and causes considerable chronic conditions, such as diabetes, cardiovascular disease, and cancer[7]. According to WHO (World Health Organization), 39% of the world population is overweight. Since many people choose to play video games over physical activities, it has been proposed to merge physical activity and gaming into one core activity through the process of exercise gamificaiton. The combination of body motions and exergaming has a great potential to be the future of physical activities[7].

Most of the exergames use metrics based on speed, acceleration, and distance to evaluate performance or scoring. We instead focus on the combination of strength, dexterity, and fine motor control, in the form of absement (time integral of displacement). We do this with audio visual feedback, to determine the ability of the user in being able to accurately represent his/her physical performance (Functional Fitness, Exergame+Functional Fitness).

Effects of bio-feedback on rehabilitation and exergames is reviewed [8]. However, most of the feedback is based on biomechanical measurements and measurements of the physiological systems of the body which require specific hardware. Besides, usage of audio visual feedback to motivate the exergame player is barely discussed [7]. Additionally, there are potential risks of injuries by doing resistance exergames such as tissue injuries and possible joint and ligament problems

Fig. 3. Head Games: measuring flow rate as a function of hydraulic head, to plot the characteristic curve of a water jet. Materials required: water pump, long hose (preferably transparent so students can see the water in it), ruler or tape measure, and measuring cup/jug (i.e. measuring "gallon"). Using a long hose, for each height of the far end of the hose, the time to fill a one-gallon jug is measured. From this measurement is calculated the flow rate (gallons per minute). This may be done by either inserting a small low-voltage submersible pump into the fountain, to supply the hose (here an 1100 GPH Rule ITT pump), or by holding by hand against one of the water jets, as shown in Fig. 6, or by insertion into a water jet by careful choice of hose diamter, as shown in Fig. 7. It is interesting to note, that for many systems, the deadhead is less than the maximum head (i.e. the curve increases and then decreases again.). The deadhead point is the point at which the hose is held so high that no water comes out of it (i.e. the pump is pushing up to the maximum water column it can sustain, as shown in Fig. 5). Often there are two points where this happens, with an even higher amount of head in between them. The "teach beach" concept makes this teaching fun and playful in the context of Stanford University's "fountain hopping" tradition. Pictured here are Prof. Mann's students Cindy and Adnan (who is also the founder of CG Blockchain and Blockchain Terminal, http://bct.io).

Fig. 4. Stanford University's fountain culture is such that at any time, people gather around, AND IN the various fountains on campus. We thus leveraged this existing culture to turn it into a reasearch and teaching lab. Here a hydraulophone (underwater pipe organ) is being tested and characterized with several low-voltage submsersible water pumps. Shown here are some of the test instruments inluding a fully submersible Fluke underwater multimeter, various pumps, fittings, etc..

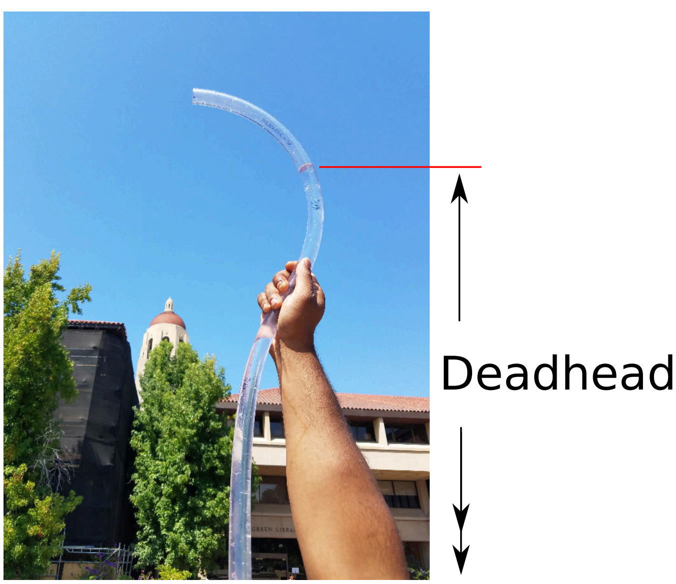

Fig. 5. Deadheading by water column: here the pump has pumped as high as it can, and the water rises no further. We simply measure the height of this water column to determine the deadhead point and plot this on the graph. Other data points require the measurement of flow rate, but here the flow rate is zero.

from applying forces constantly in unnatural postures [9].

While exercising can improve one's fitness, incorrect movement/posture can lead to injuries [10], [9]. In order to help with exercising in a proper posture, an integral kinesiology system is developed in this paper. This system adopts an audiovisual feedback system to effectively motivates the subjects to train with the right posture and improved results.

A more comprehensive integral kinematics based exergame design has been submitted to ACM Mulimedia 2018, and is currently under review. This paper provides the first in depth analysis of the data, and shows a direct proof for the efficacy of the exergame system in terms of performance improvement.

II. Fitness Game Design and Data Collection

The goal of the game is to allow the subject to strengthen the core muscles and ultimately improve the overall body balance [11] and other functional movement skills. An integral kinesiology board (a smart wobble board manufactured by Mannlab Shenzhen) is provided to allow the subject to use the body as a joystick to tilt towards a destination goal while maintaining high stability. The goal starts at the center of the board, then moves around like a driving game. An IoT enabled accelerometer was created with a sampling rate of 50

Fig. 6. Head Games played by connecting a hose to one of the water jets in a splash pad aquatic play area. A ruler is used to measure the hydraulic head (height of water column) and a measuring cup is used to measure the amount of water flowing in a given time to determine flow rate. In our final teach beach^{TM}, we envision that the jets would be designed for easy coupling to hoses which would be lent to participants so they don't have to bring their own as we did here. Rightmost: exploring interference patterns between waves formed by Karman vortex shedding in bluff bodies (in this case, fingers) inserted into moving water. Karman votex shedding is the principle of operation of some hydraulophones. The fingers are roughly cylindrical, and the Strouhal number (St) (dimensionless quantity characterizing oscillating flow mechanisms) of a cylinder is approximately 0.18.

cycles per second which sends coordination of each axis using MQTT [12] to a mosquito broker [13] on a log server allowing us to gather the data from subjects.

A mobile application was developed to provide feedback and motivation to the subject from two perspectives: the highest personal record, and a real-time audiovisual displacement indication. As the subject moves away from the goal, the background music is distorted by changing its pitch, and a ball in the centre of the screen dislocates proportionally.

A scoring system has been designed based on the framework of Integral Kinematics. The time integral of displacement (absement) is used as a metric to evaluate the performance, rather than the time differential of displacement (velocity). To minimize the absement, the subject has to be as stable as possible (minimize displacement) during the exercise period(time).

In order to validate our study, we recorded data from 12 participants. Two experiments were conducted. In the first one, subjects are asked to perform a 60-second plank on a MannLab board. The goal is to minimize shake (stability). Subjects are asked to perform planking twice, once without any feedback, and once with the cellphone application. The second experiment is the same setup, excepts that the time limit (60s) is removed to see the effects of our system on both time and stability. The goal is to minimize shake while maximizing time (plank as long as possible), and again we had participants do this once without any feedback, and once with the cellphone app.

The recorded data were normalized and the absolute angular value was calculated based on the accelerometer reading in radians. The absement was estimated by the area under the absolute angular displacement curve.

III. Results and Discussion

Figures 10 and 11 show the results of a participant performing the first experiment shown in Figure 9. During this 60s standard test, the calculated absement is much smaller for the feedback-enabled test. By observing the displacement distribution, we can see that the stability is much better for the feedback-enabled trial.

The second experiment result is shown in figure 11. The subject showed an increase in duration (time) for 38.1%, and a decrease in average absement for 6%.

The data reveals a strong relationship between absement and stability, as shown in figure 12. When the subject is more stable (less relative displacement from goal), the absement will increase slower, and vice versa, when there is more shaking, the absement will increase faster. Currently, there is no quantitative way to accurately measure balance and stability, absement shows a great potential to fill the gap.

A larger scale test will be conducted to further investigate the validity of our system. Also, some preliminary results have shown that this system could be helpful for rehabilitation and muscle disorder identification.

IV. Conclusion

We introduced the concept of Integral Kinesiology, which arises from absement, a new quantity which itself arises from hydraulics (hydraulophones, water flow, etc.). Integral Kinesiology is based on activities that test and develop a combination of strength and dexterity. Activities such as deadheading, are ideally suited to developing this skill. We created an interactive virtual deadheading studio environment for immersive/submersive aquatic play experiences. Additionally, we developed a game with absement scoring that has proven its effectiveness in motivating people to improve their exercise results. For exercises that do not only rely on speed

Fig. 7. Head Games played by inserting a hose into an existing water jet in one of Stanford University's fountains. Here a hose of 3/4 inch outside diameter was found to fit perfectly. This is a nice calm fountain with relatively low head. Thus Head Games™can be played easily with a modest length of hose. Left: underwater photograph showing insertion coupling. Right: Virtual Reality with video-see-through allows information to be overlaid on the water jet for teaching and instructional purposes.

Fig. 8. Head Games™climbing wall. Here a participant experiences head by touching the water jet from various heights. Calculations are rendered in the virtual world, where the eyeglass actually operates in a "multimediated reality" mode, using video see-through and overlay of water jet attributes with actual water. Left: deadheading the jet results in much higher head, but coming away from it results in much less head. Middle: the head increases again as we move down. Right: further down the head increases, due to further potential energy transferred to kinetic energy.

and strength, integral kinematics provides an alternative way to evaluate the performance.

V. Acknowledgements

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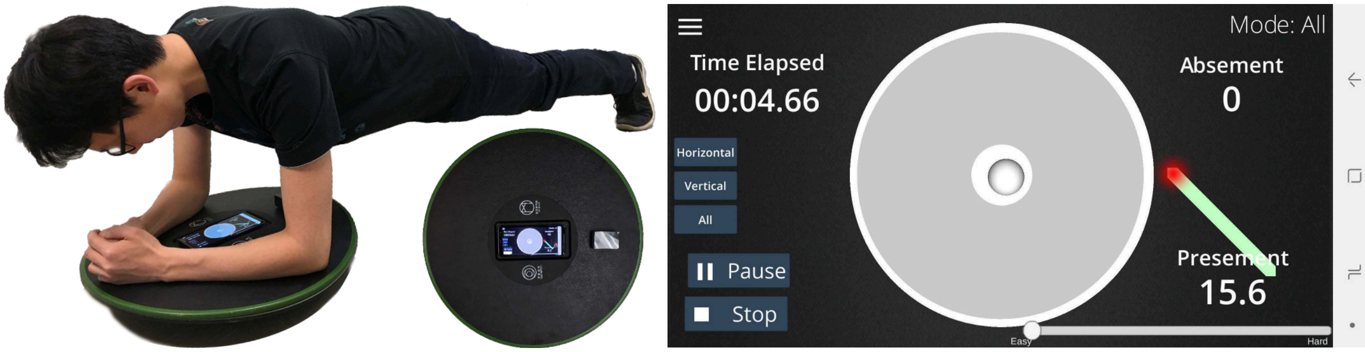

Fig. 9. Plank on a MannFit™ Board with visual-audio feedback.

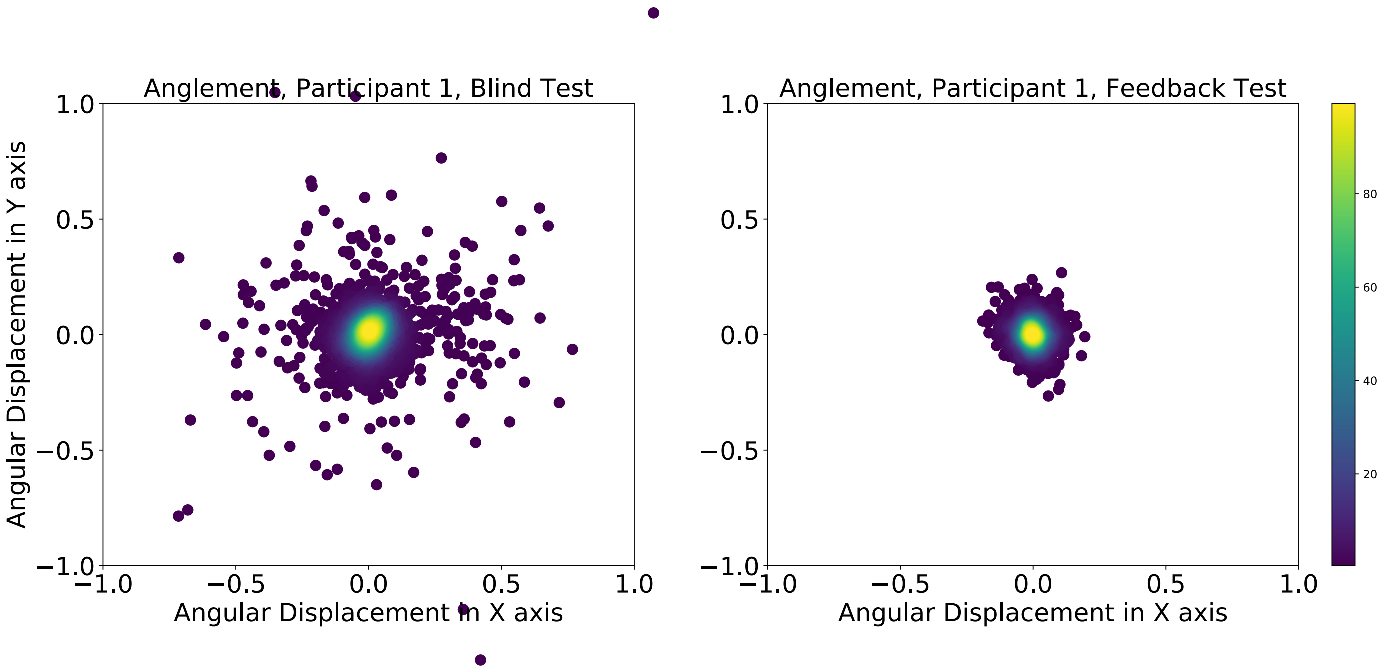

Fig. 10. Displacement distribution during a 60s plank test for one subject without any feedback (left) and with a audiovisual feedback (right). X and Y are axes of tilt during the planking.

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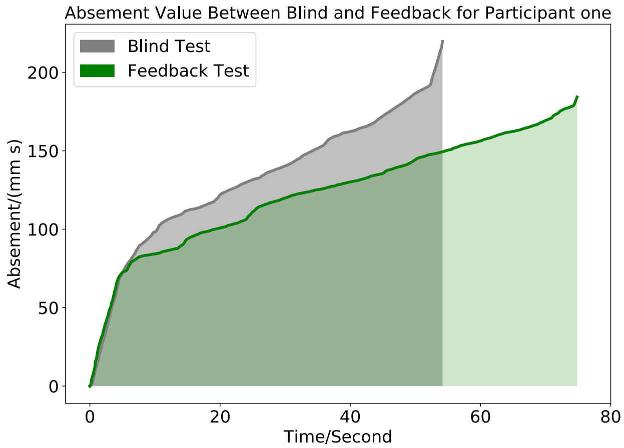

Fig. 11. Comparison between Integral Kinesiology with and without feedback. The subject performs two plank tests with the goal of maximum time and stability. The grey line indicates planking without any feedback (blind), and the green one, with audiovisual feedback.

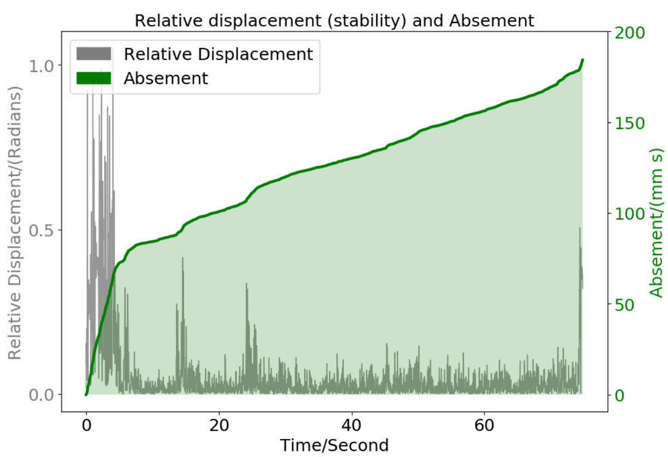

Fig. 12. Relative displacement (absolute value) and absement value over time. We can see that there is a lot of shaking with a fast increase in absement at the beginning.