TRAINING PROPRIOCEPTION AND TOUCH FOR BALL HANDLING IN SPORTS

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ABSTRACT

Having a good sense of touch and proprioception is essential for ball handling in ball sports. Handling a ball requires the player to pay as little attention to the ball as possible in order for him to be able to pay attention to the other players around him or to the circumstances of the game. In order to do that, players need to develop their touch and proprioceptive senses and their mental system for managing their peripersonal space. Two approaches are described herein that allow players to train those senses to enhance their ball handling skills.

INTRODUCTION

Many of the activities performed by us rely on the automatic and instinctive control of our body. An area where this is particularly important is sports, particularly ball sports. For example, when a soccer player is handling the soccer ball and has to go past several opponents, he needs to pay as little attention to the ball as possible in order to be able to pay attention to where the opponents are and anticipate their intentions. The same happens in other sports such as basketball, handball, hockey (where rather than a ball there is a puck) and others. In these circumstances, the player needs to control the ball in a way that is as automatic and instinctive as possible.

As Stephan Curry explains in an interview to CSN about his training methods with Brandon Payne: "*When we are out playing, there are so many things you have to think about[...]. The last thing you should be thinking about is where the ball is. [...] That should be second nature*." ("Stephan Curry's interview to CSN," 2015)

The way to achieve this "second nature" ball handling is to train one's instinct, namely the sense of touch and proprioception and the command of the whole system that manages the peripersonal space.

NEURAL BASIS

When a soccer player is handling a soccer ball around other players, touch allows him to feel the contact with the ball. Proprioception allows him to feel his limbs and where they are located, particularly the foot he is using at this moment of contacting the ball. By combining touch with proprioception, the brain can identify the position where the ball is located and the direction and speed that the ball will take after the contact.

Even when the foot is not in contact with the ball, the brain can keep track of where the ball is located. This is achieved by brain maps that control the peripersonal space. The peripersonal space is the space immediately surrounding the body, including the objects that exist in it (Rizzolatti, Fadiga, Fogassi, & Gallese, 1997). These brain maps are supported by sensory information that comes, mostly, from vision and touch. It is based on several types of neurons that respond to the visual and or tactile stimuli created by an object that is located near the body. Some of these neurons are monomodal and only respond either to visual stimuli or to tactile stimuli (Graziano, Yap, Gross, & others, 1994). Others are bimodal and can respond to both types of stimuli (Làdavas, Farnè, Zeloni, & di Pellegrino, 2000; Rizzolatti et al., 1997; Wolpert, Goodbody, & Husain, 1998).

Training proprioception and touch and the system that manages the peripersonal space requires training the neural paths that the brain uses to put those capacities into action. The problem in ball sports is that when an athlete starts training his ability to ball handling, he often does it while looking at the ball, besides touching it. That is, the player is relying both on the visual system and on the proprioceptive/touch systems.

The reason this is a problem is that when two neural pathways can be used to perform an action, the brain usually focuses on the easier one, thus leaving aside the weaker one (Doidge, 2007). Because the visual path is the easier one in this case, the brain will not rely on the proprioceptive/touch path as much and, as a result, it will not develop it as far as it could.

This would not be a problem if despite engaging the visual path the proprioceptive/touch system would also be equally engaged nonetheless. However, there is evidence of the relative independence between of the visual and the touch/proprioceptive paths. For example, M F S Rushworth, Nixon, & Passingham (1997) found, working with monkeys, that if a given neural area related to proprioception was damaged, the monkey would be able to reach the object if it was seeing it, but not if it was not and had to rely on proprioceptive information. Conversely, if it was the proprioceptive that was in good condition and it was the visual area that was damaged, the monkey would not be able to reach the object when it was seeing it, but it was able to do it in darkness when it was being guided by proprioceptive information. In other experiment Rushworth, Ellison, & Walsh (2001) found that spacio-visual attention and motor attention related to finger movement are handled by different neural areas.

Moreover, it has been observed, for example, that some hand related neurons respond to touch if the person can see the area that is being touched, but that they barely respond if she cannot see it. In contrast, shoulder or face related neurons have a greater response to touch (Làdavas et al., 2000). Because hands are easy to see, the person relies on vision when using them, and does not develop touch so much. On the other hand, the shoulder is rarely seen and the face is never (directly) seen, so touch related neurons must be used directly more often, and therefore they develop more.

In conclusion, all this suggests that in order to develop the neural areas related to proprioception and touch, it is necessary to make sure that proprioception and touch are being used.

A way to develop a neural pathway that is in competition with another easier pathway is to block the easier one, so that the brain is forced to use the path that needs to be developed. This approached was used for example by Taub & Uswatte (2003) to create a novel rehabilitation technique for certain types of motor deficits that are caused by stroke and other nervous system problems. If the patient has problem moving one arm, the technique works by constraining movement of the less affected arm by using means such a sling. When the patient's brain perceives that it cannot move the arm, it resorts to the neural paths that guide movement of the affected arm and starts developing them again.

TWO CURRENT TRAINING APPROACHES

In basketball, Stephen Curry practices a training technique with Brandon Payne that shares some basis with Edward Taub's constraining based approach to rehabilitation. The goal of the technique used by Curry is to develop the proprioceptive and touch pathways that will allow him to handle the ball instinctively, without looking at it and paying conscious attention to it. In order to do that, Curry is handling a basketball with one hand while, at the same time, is handling a tennis ball with the other. The tennis ball is smaller than the basketball, so he must pay close attention to it. As a result of this, he is forced to handle the basketball without looking at or pay attention to it. To make the training deeper, Curry performs the drill while he is wearing a pair of strobe goggles. Strobe goggles comprise liquid crystal glasses that switch rapidly between transparent and opaque states, thus disturbing vision. This forces Curry to pay even more intense attention to the tennis ball ("Stephan Curry's interview to CSN," 2015).

Another application which shares some traits with this one is the one developed by the company Cognisens (Cognisens, 2015). Their goal is to help players develop cognitive skills for tracking several players simultaneously during a match. For that, they have developed a computerized 3D multiple object tracking (MOT) activity in which several identical objects are moving on a computer display. The player's goal is to focus attention on some of those objects and keep track of them as they mix with the rest of the objects. Their training protocol ads a physical task for the player to perform while he is carrying out the MOT activity and paying attention to the objects. The protocol gradually increases the difficulty of the physical task that the player performs. At one point, the physical task will have the player paying attention to the objects in the MOT while handling a hockey puck.

In contrast to Payne and Curry's drill, this protocol has the direct goal of helping the user to optimally learning the MOT activity, rather than learning ball handling. Cognisens incrementally adds a physical task because they have found that if subjects are performing a physical task when they start learning, their ultimate learning will be poorer (Faubert, Sidebottom, & others, 2012). This happens even with as simple a task as standing while doing the MOT learning. In summary, rather than learning ball handling, Cognisens' goal is help players learn multiple player tracking while performing other tasks, as might be ball handling.

However, Cognisens' protocol could also be interpreted in the reverse situation. By having the athlete perform the MOT activity, his brain is forced to focus on it, and therefore must perform the side physical activity using proprioceptive, touch and other instinctive resources, therefore developing them.

NEW APPROACH: GAZE CONTROLLER

A new approach to train proprioception, touch and management of the peripersonal space is based on a new product. This product is built upon a device that measures the direction of the person's line of gaze and affects it or gives some kind of feedback when it is directed to the undesired way.

A way to implement the product is based on a pair of spectacles upon which several additional devices are mounted. When combined, these devices can measure the direction of the person's gaze and affect it. As shown schematically in **Figure 1**, when the player is looking forwards, he can see normally. When he is trying to look at the ball, the lenses turn opaque and he cannot see the ball.

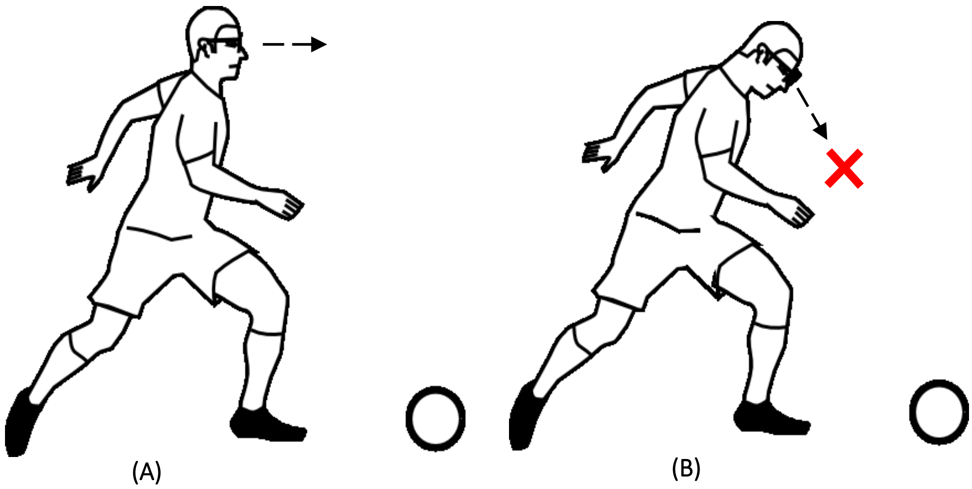


Figure 1. (A) The player is looking forwards, and the lenses are transparent. (B) The player is looking downwards trying to see the ball, and the lenses are opaque.

The spectacles' structure is schematically represented in **Figure 2.** As described in the Figure, the first device that is attached to the spectacles frame is a gyroscope (marked as '2'). This gyroscope measures the angle that the spectacles form with the horizontal plane (or other plane that might be taken as reference). When the user tilts his head to look down, the gyroscope senses this tilt and if the angle goes beyond a given threshold, it can produce a reaction that will be described later. The gyroscope only measures the inclination of the head, so if the user merely rotates his eyes downwards, the gyroscope will not be able to sense it.

The second device attached to the frame is an eye-tracking system. This system comprises a pair of mini-cameras (marked as '3L' and '3R' for left and right eyes in Figure 2) that point to the eyes, and which are connected to a software that tracks the direction of the eyes' line of gaze. In contrast to the gyroscope, this eye-tracking system only measures the gaze direction with respect to the spectacles frame. If the user moves the head to look down but does so without rolling his eyes in any direction, the mini-cameras will not notice it.

When both devices are combined, a measurement is obtained of the eyes' line of gaze with respect to a reference plane, such as the horizontal plane. Therefore, when the user looks down to see a soccer ball or a basketball, the system can detect it.

The third device added to the frame is a pair of lenses for the spectacles frame. These lenses (corrective or not) are made of a material, such as liquid crystal, that can be turned opaque or transparent with an electrical stimulus. They have become well known in recent years because they have been used to create this strobe effect glasses. This kind of glasses were mentioned above in relation to the strobe glasses that Stephen Curry uses in his training. In the current product, they are used so that when the user's line of gaze is pointing in a direction that is not appropriate, the lenses will be made opaque and therefore will prevent the user from seeing in that direction.

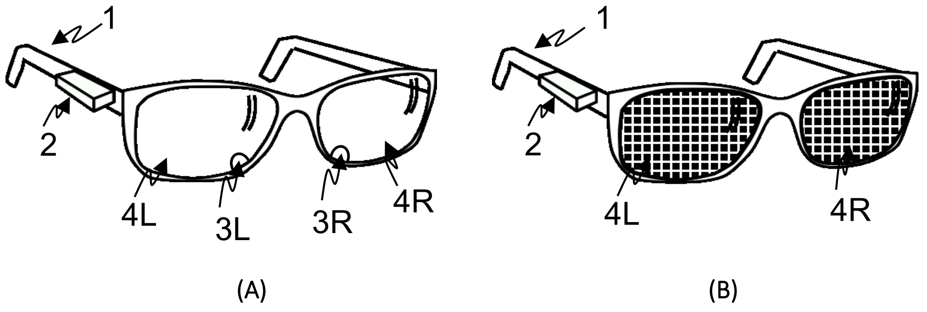


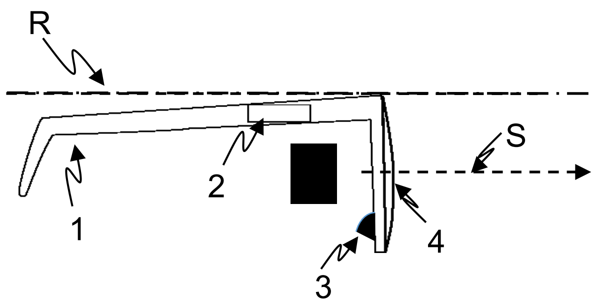
Figure 2 (A) The frame '1' contains a gyroscope '2' that senses the inclination of the frame, an eye-tracker system that contains cameras '3' for left and right eyes and two lenses '4' that are turned opaque when the user's line of gaze is directed downwards beyond a given angle. (B) The lenses '4' have been turned opaque. (Additional electronics necessary to make these elements work together is not shown)

Figure 3 shows schematically how these devices work in combination. The system uses the gyroscope and the eye-tracker device to measure the angle created between the user's line of gaze and the horizontal plane. When the user is looking down beyond a given angle (presumably looking at the ball) the system turns the lenses opaque, so that the player will not be able to see the ball. The result is that the user is obliged to handle the ball using touch, proprioception and his system to manage the peripersonal space, thus developing those systems and their related abilities.

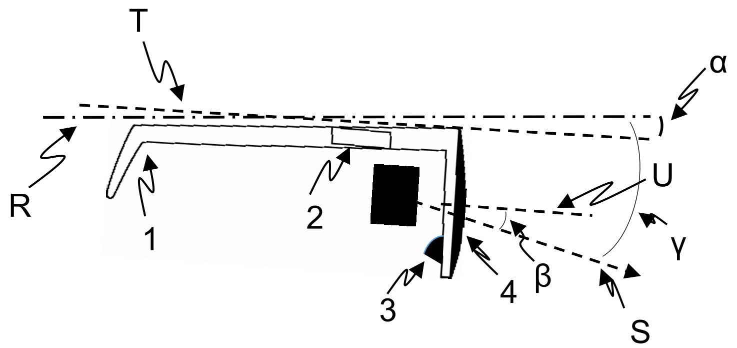
In order to make the experience as natural as possible, the lenses might turn opaque gradually in time. Or even, gradually along the vertical axis, making the bottom part more opaque than the upper part, and even leaving the very top in a transparent state permanently. Furthermore, rather than making the lenses opaque, it would be possible to block vision sufficiently, for example by reducing their transparency level or, with a different technology, making the lenses blurry.

An important issue is: Why have a system that prevents the player from seeing the ball rather than just instructing the player to refrain from looking at it? The reason is that three problems arise if the player just refrains from looking at the ball.

The first problem is that for the player to being careful not to look downwards, he must be paying attention to himself. However, it has been found for better learning the player should have an external focus of attention, not internal (McKay, Wulf, Lewthwaite, & Nordin, 2015; McNevin, Shea, & Wulf, 2003; Wulf, Höß, & Prinz, 1998)



(A)



(B)

Figure 3. (A) The line of gaze S is parallel to the horizontal plane R; the lenses '4' are transparent. (B) The line of gaze S defines an angle γ with the horizontal plane R which is the sum of the angle β that it defines with the frame plus the angle α that the frame defines with the horizontal plane. This angle γ is considered to be beyond a given threshold, and the lenses '4' have been turned opaque.

The second problem is that by paying attention to where he is looking at, the player will be doing two actions at the same time rather than just putting all his resources into one.

The third problem is that by reflecting on and paying attention to himself, the player might be interfering with processes that work better when left alone (Beilock, 2010)

Moreover, if the player has been practicing looking at the ball for a long time since he started training the sport, he will have become used to it, and therefore will have a strong tendency to keep doing it instinctively. Therefore, it will be difficult for him to stop doing it, and he will need to put a lot of attention for controlling that habit. Finally, it should also be kept in mind that Edward Taub's constraining based rehabilitation is based on constraining the patient to move the less affected limb rather than on instructing him not to move it.

Different variations can be performed on the above described apparatus. It is possible to create simpler versions by just adding a gyroscope or an eye-tracking system alone. Despite this would have reduced functionality because it will only allow to sense head position or eye position, it would be cheaper to build. Also, the apparatus can be built by appending lenses on a helmet or any other head-worn device. The software and hardware necessary for the system to work can be embedded in a small box that would be attached to the frame, or in a box that the person would carry for example on a jacket which would be connected to the frame's devices by a cable or by radio waves.

Finally, it is possible to create an even more affordable, despite limited, version by using just a frame and creating in shape in such a way that it does not allow the wearer to look downwards. Two examples are shown in **Figure 4**.

(A) (B)

Figure 4. A simple plastic frame to prevent the player from looking downwards and develop ball 'feel'.

PERIPHERAL VISION

The described spectacles-based product provides two additional benefits regarding peripheral vision. Peripheral vision is considered to be a key ability for sports that involve open activities and the athlete has to react to a changing environment full of different sources of information. For example, a football goalkeeper that wants to intercept effectively the ball has to be able to quickly read the different signals sent by the different parts of the body of the adversary having the ball plus the considering positions of the other players around him.

To see the role of peripheral vision it is important to consider the following. In general terms, when the brain uses vision to extract information from a given scene, it does so by fixating the eyes on one point of the scene (Rayner, 1998; Rayner, Schotter, Masson, Potter, & Treiman, 2016). When the eyes move from one point to fixate a different point to extract information from it, the movement that is performed is called a saccade. A saccadic movement requires approximately 40ms to be completed, and during this time vision is suspended in a process called 'saccadic suppression' (Rayner, 1998; Rayner et al., 2016). Despite the perceived speed with which the eyes move, performing a saccade to fixate a given point requires approximately 200ms of advance motor planning. That is, once the brain has perceived a stimulus, it needs around 200ms to be able to organize the muscle movements that will fixate the eyes on the source of that stimulus. One can easily get a feeling of this limit by trying to repeatedly move the ayes between two different points to fixate those points.

However, a goalkeeper that needs to keep track of many sources of signals cannot simply rely on moving eyes very rapidly to fixate from point to point because of two reasons which are based on the above mentioned facts. The first reason is that, due to saccadic suppression, during the time his eyes move, the player is functionally blind. In the hypothetical case that a player was able to make 25 saccades in a second, he would not be able to notice anything from the environment. The second reason is that due to the time needed to plan the motor actions required for a saccade, he would only be able to fixate around 5 or 6 points per second.

As a result, it is considered that expert players rely on information that they gather from the context by peripheral vision besides the one gathered from gaze fixation. However, this has been difficult to prove experimentally. Moreover there is some apparently contradictory evidence about this point. On the one hand, it has been found in some circumstances that expert players perform less saccades than novice players, which leads to believe that expert players can extract more information from each fixation. However, in other situations it has been found that expert players perform more saccades than novices. This apparent contradiction might be due to the fact that in some circumstances expert players are able to realize that they need to perform more saccades while at the same time extracting more information from peripheral vision. However, the jury is still out there on it (Ryu & 柳東賢, 2014; Williams, Davids, & Williams, 1999).

The benefits that the spectacle based apparatus provides for peripheral vision are two. First, it allows the player to train peripheral vision while handling the ball on the pitch. Second, it allows the sport scientist to learn about what role peripheral vision has on handling the ball.

This comes from the fact that the spectacles prevent the user to fixate on the ball, but they allow him to gather information about the ball via peripheral vision coming through the bottom part of the lenses and through the space that lies between the lenses/frame and the cheek, as shown in **Figure 5.**

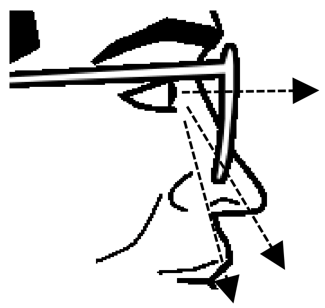


Figure 5. Despite being forced to look forwards, the player can see downwards using peripheral vision

In relation to training, if the player wearing the spectacles needs to gather information about where the ball is, his brain will be forced to resort to peripheral vision, given that his eyes cannot look at the ball. His direct-vision path is blocked, so his brain must use this indirect-vision path, developing his ability for peripheral vision.

In relation to learning about the importance of peripheral vision, the device allows for comparing the performance of player who can peripheral vision and those who cannot. This is done by blocking vision through these openings (**Figure 6**) and comparing ball handling between players for whom this part is blocked with players for whom this part is open.

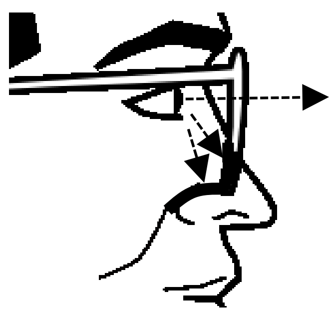


Figure 6. Blocking peripheral vision for investigation purposes

Furthermore, eye-tracking glasses are equipped with means to record data while they are being used, including data about where the user is looking at. This facilitates to analyze players' line of gaze and compare those players that keep the line of gaze as low as possible without turning the lenses opaque and those who keep a line of gaze more parallel to the ground. The assumption would be that those players keeping a low line of gaze would be benefiting more from peripheral vision on the ball.

NEW APPROACH: CONTINUOUS FOOTBALL

This application's goal is facilitating the user to compress a great amount of practice to train his neural systems devoted to "feel" the ball. Skill development requires both practice quality and quantity (Van Mullem, 2016), and this approach is directed to increase both. It can be used while wearing the gaze controller spectacles or without then. If not wearing the spectacles, the player will still benefit from it because he will have to pay attention to certain stimuli that will make it difficult for him to look at the ball.

Continuous Football can be put into practice in two different variations, as described below

Football Path

The first variation to this approach is based on arranging certain equipment along a given path that the player must complete while keeping control over the ball. The equipment will force the player to execute actions that will enhance his learning.

Let us take a quick look first to a very popular drill for training skills. It involves zig-zagging around cones, as shown in **Figure 7**.

Figure 7. A standard drill is zig-zagging around static cones.

The problem with this drill is that the cones are static, so the player knows beforehand what move he will need perform. The player is training the move, but he is not training the decision to instantly executing it in response to an external stimulus.

Football Path is a product that allows to perform a similar drill but in a dynamical way. A way to implement it is arranging equipment as shown in **Figure 8**. One or more obstacles will be moving along with the player and will interfere in his path.

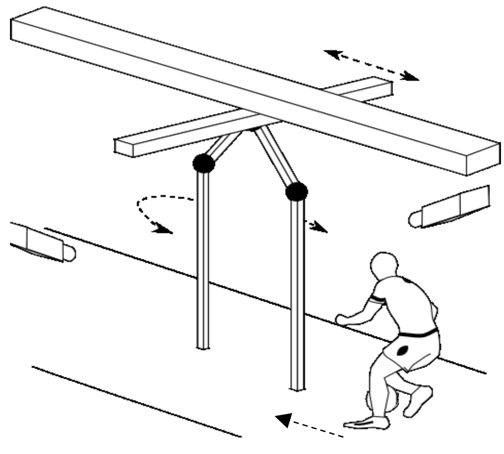


Figure 8. A new drill is zig-zagging around some obstacles that appear dynamically.

The player will then have to make the decision to perform a reaction move without having had time beforehand to plan it. The player will need to be paying attention to the obstacles, so he will develop his skills for handling the ball based on 'feel'.

A computer controls the obstacles, and presents them in a way that depends on the player's skills and is optimal for his development. Two or more cameras are filming the drill and specialized programs are analyzing the position of ball and player. The player wears some markers on his clothing to facilitate this analysis.

Another way to implement Football Path is shown in **Figure 9**.

A computer and two mechanical arms move along two handrails.

The computer shows a cognitive activity which requires the user to respond by touch on the screen.

The mechanical arm structure slides along at a defined distance from the computer.

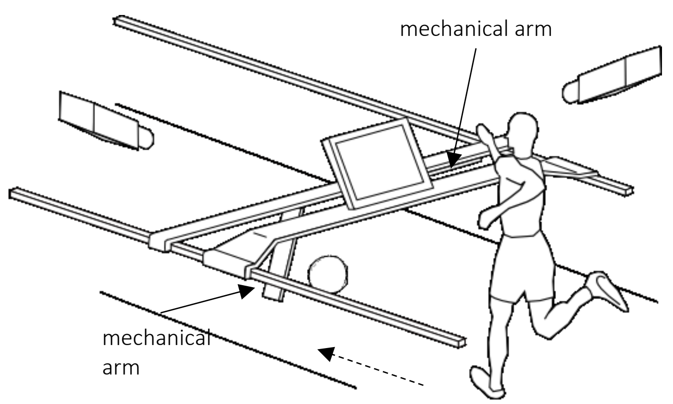


Figure 9. A new drill is performed by running as fast as possible along a path while maintaining the ball far from two mechanical arms. The left mechanical arm is open and impacting on the ball.

The player has to run as fast as possible while at the same time keeping the ball sufficiently close to him to prevent it from being impacted by a mechanical arm. The shorter the distance between the mechanical arms and the computer, the more difficult the drill is. In **Figure 9**, the ball has got too far away and the left mechanical arm has fired to impact on it.

As before, two or more cameras are filming the drill and specialized programs are analyzing the position of ball and player. This position analysis is used to slide the computer at the right speed to keep close to the user, and to evaluate whether the ball is close to a mechanical arm and, if so, to fire the mechanical arms to impact on the ball.

This device forces the player to control the distance of the ball while he is running. This is a critical part in a football match. Having the ball far from the feet allows to run faster, but gives more opportunity to adversaries to steal it. Football start Lionel Messi is usually acclaimed for his ability to run having the ball “glued” to his feet.

There are other ways to implement and use this product. In general, all of them the player will have to pay attention to some stimuli while at the same time performing a football activity that will help him to develop ball handling skills.

Football Treadmill

A second variation to implement Continuous Football is using equipment similar to the one shown above but installing it together with a running treadmill.

A treadmill is a different environment than a football pitch and the biomechanics of running on a treadmill is different from that of running overground. It has been found that running on a treadmill involves a faster step cadence (Riley et al., 2008), and that sprinting on a treadmill requires less energy (Frishberg, 1982).

However, treadmills provide some advantages for training skills. It is a much more controlled environment which allows for a finer control of the training variables. Moreover, given that running on the treadmill usually involves a faster step cadence, the player will need to touch the ball more times per time unit and will have less time to prepare for it. Furthermore, because it demands less energy from the runner, the player can spend more time training ball handling.

As in Football Path, there are different ways to set up the equipment to perform drills. The first one is similar to the one that was shown before in **Figure 9**, and is schematically illustrated in **Figure 10**. It. The player would be running on the treadmill while at the same time would be handling a football with his feet as if he was running on the pitch. Ball position can be measured by different means, and in this case is measured by a set of lasers that emit several rays that are detected by photoelectric sensors.

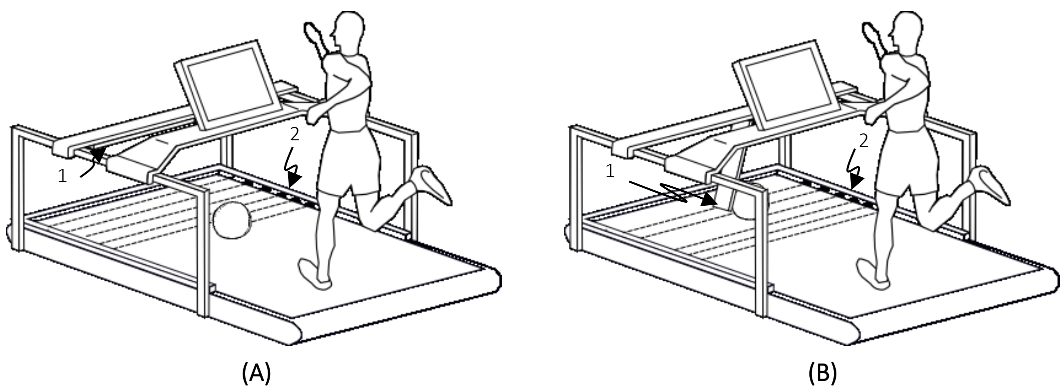


Figure 10. A running treadmill is enhanced with a computer, a mechanical arm '1' , and position sensors '2' to facilitate training the instinctive handling of the soccer ball. (A) The ball is not in the path of the photoelectric sensors, and the mechanical arm is at rest. (B) The ball is in the path of the photoelectric sensors and the mechanical arm has been fired to intercept the ball.

In this setup, the computer display shows game situations in which the adversaries are farther or closer to the treadmill user. Depending on where they appear, the user knows that he can keep the ball at a larger distance or that he must keep it at a shorter distance. He then can decide to run at an adequate speed that allows him to keep control of the ball. The computer is synchronized with the mechanical arm so that depending on the distance at which adversaries are located on the computer display, the computer moves the mechanical arm farther or closer, and allows the user to keep the ball at larger or smaller distances. This helps the player not only to learn to control the ball instinctively, but also to instinctively adapt to the circumstances of the match.

As with Football Path, this system can be implemented in different ways. For example, **Figure 11** shows how a sliding mechanical arm with no computer display can be used to put more or less pressure on the player's handling skills. An external computer slides the arm closer to or farther from the player. The player would pay attention to the position of the dummy and would have to trade speed with ball distance. **Figure 12** shows how one or more articulated arms can be used to present moving obstacles to the player, as he runs on the treadmill. The player has to avoid the obstacles as they move towards him while at the same time keeping control on the ball. This treadmill is wide, so if it was used for the setup of **Figure 10** it would also allow the user to move right or left to virtually dribble an adversary that might appear on the computer display.

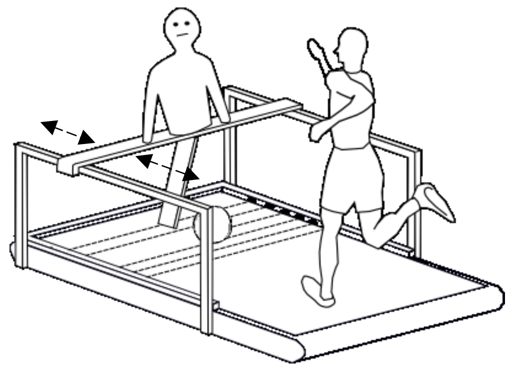


Figure 11. A mechanical arm controlled by a computer is mounted on a sliding bar. It can get closer to the user, so that he has to handle the ball with more care, or farther from him so that he can run faster. A dummy allows the user to more clearly see the arm's position.

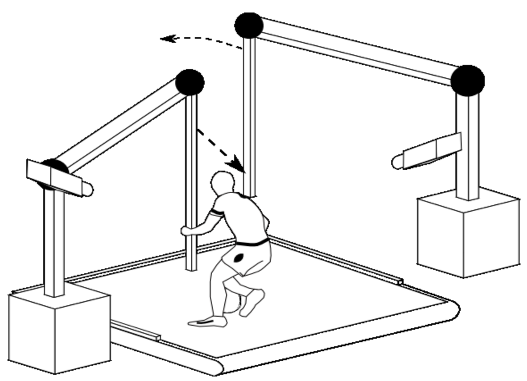


Figure 12. One or more articulated mechanical arms are used as obstacles for the user to avoid them while keeping the ball under control.

A beneficial add-on for some of the manners in which this product can be implemented is an automatic system to allow the player to automatically change the treadmill speed. Different ways to perform this speed adjustment have been described in the literature (Kim, Stanley, Curatalo, & Park, 2012; Minetti, Boldrini, Brusamolin, Zamparo, & McKee, 2003).

CONCLUSIONS

Athletes in ball based sports need to develop their touch/proprioceptive and peripersonal management systems in order to be able to manage the ball instinctively while they are paying attention to teammates and adversaries. Modern sport coaches such as Stephen Curry's follow training regimens that facilitate this development by having the athlete manage a ball while simultaneously have his attention is directed elsewhere.

Two additional approaches have been described that allow to train these skills particularly for football, but which are applicable to other sports as well such as basketball. The first one is based on a spectacle apparatus that measures where the athlete is directing his gaze. When the line of gaze is interpreted to be directed down towards the ball, the apparatus turns the spectacle lenses opaque. Because of that, the player will automatically refrain from looking down and will have to rely on touch and proprioception to handle the ball, thus developing those systems and related abilities.

The second one is based on providing the necessary equipment for the player to continuously perform a football task. This can be put into practice in two variations. In the first one, some equipment is laid on a training field that forces the player to run and evading obstacles while at the same time keeping control of the ball. In the second one, similar equipment is attached to a running treadmill on which a soccer player would run while handling a soccer ball with his feet. A computer can be added to the path or treadmill versions that displays a cognitive task for the player to perform while he is running. In both cases, the system captures the player's attention and forces him to handle the ball relying on his touch and proprioceptive systems, thus developing them as well.

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