

## CHAPTER 1

# PRACTICE MADE PERFECT

It was just one of dozens of snaps Stanford's quarterback Kevin Hogan would take that day against the Maryland Terrapins at the 2014 Foster Farms Bowl. The coaches had called for a simple running play, "95 Bama," which required Stanford's wide receiver to block one of Maryland's safeties after Hogan handed the ball off to his running back. But as the teams lined up, Hogan noticed a subtle change happening in the Terps' defensive formation. Their safeties began shifting positions, making it impossible for that crucial block to be made. Hogan realized if he didn't change the play in the seconds before the snap, the unblocked Maryland safety would stop the running play cold, leaving Stanford with a loss. So, exercising the kind of on-field decision-making that is crucial for a quarterback's success, Hogan killed the original plan and changed to a different running play, which would allow Remound Wright, his running back, to exploit the new space in the Terps' defense.

The call resulted in a 35-yard gain, and was just one of hundreds of small decisions Hogan made that day to help Stanford to a convincing Bowl victory. Hogan was later asked how, in that split second, he recognized the opportunity to change the play.

“It was easy,” Hogan told the journalist. He was familiar with the Terps’ blitz. He’d already seen it countless times with his own eyes, through a virtual reality training program adopted by Stanford earlier that season.<sup>1</sup>

When you picture big-time college or professional football, images of brutal physicality and stunning athletic feats come to mind. And for a few intense hours on any given weekend, that’s what football fans get—crunching tackles, balletic catches, deft touchdown passes, and other displays of sublime athleticism. This is what fans see on ESPN and in YouTube highlight clips, and because of this focus on the extreme physical aspects of the game, it is easy for casual fans to forget how cerebral football at the highest levels is, not just for the coaches, but for the players as well. This focus on the mental aspect of the sport is reflected in the way teams train for games. Unlike athletes in most other team sports, who prepare by doing drills or scrimmaging, the reality of preparation for a football player is often more prosaic: much of the time is spent poring over playbooks and watching game film in order to learn the extensive, customized offenses designed by modern coaching staffs.

In football circles, the process of learning all these plays is called “installation,” as if the players were human computers uploading a new operating system. But people are not computers, and the act of learning an offense is not done passively. It requires hours of rigorous, focused study. In the morning before practice, and in the evenings before bed, Monday through Saturday, from summer to winter. Over and over and over again. There’s no other way to memorize these intricate game plans, so that, when it’s time for

kickoff, they have become so well ingrained that a player can carry them out unconsciously. Getting these plays right, and executing them effectively, is vital to a team's success. It is no surprise that in the big business of college and professional football, franchises spend a lot of time and money developing systems to improve this process. And no player is more responsible for implementing these systems than the quarterback.

Consider NFL veteran Carson Palmer. During the typical week of a season, the Arizona Cardinals' quarterback and his coaching staff will whittle an initial playbook of 250 unique plays down to about 170.<sup>2</sup> Each has to be studied and memorized. This includes not just the basic formations, positions, and movements of his teammates, but all the related information: What is the defense of this particular opponent likely to do? What should Palmer's response be if the defense changes its formation? If it's a passing play, which receiver gets the first look from the quarterback, and which one is the last resort? These various contingencies, too, must be learned, and they must be learned for *each* play. It's a dizzying amount of information, and in order to take it all in by game time Sunday, Palmer has adopted a disciplined regimen of almost continuous study. Each week during the season, Palmer and other top-level quarterbacks are like students with only a week to cram for their finals—a test which will be broadcast to tens of millions of viewers and dissected mercilessly on ESPN and sports radio the next day.

Palmer's week of intensive study usually starts on Tuesday night, after the coaching staff sends over the playbook for the following Sunday's (or in some cases, Monday's) game. During practice on Wednesday through Friday, the team will run through these plays. Traditionally, these practice plays will be captured on video and digitally catalogued, so players can review them on their com-

puters or tablets off the field until they know them cold. But since the 2015–2016 season, the Arizona Cardinals have added the same VR technology that Kevin Hogan used at Stanford in 2014. On mornings and evenings before practice, Palmer slides on a headset and reviews practice footage captured with a 360-degree camera that has been mounted behind him on the practice field. When Palmer puts on the Head Mounted Display in his home office, he is instantly transported back to the moment in practice that he is reviewing, enveloped by an immersive re-creation of the play in which his real-life perspective of the unfolding action is reproduced almost exactly as he sees it on the field. For Palmer, and a growing number of professional, college, and even high school quarterbacks, virtual reality has literally been a game changer.

Palmer has seen a lot of different kinds of technology in his football career. When he was in high school in the late 1990s, he was still using a classic playbook, a three-ringed binder filled with hundreds of pages of Xs and Os diagramming formations. By then, film was ubiquitous: practice and game footage would be captured on videotape, filmed from a camera high up in a stadium press box for later study and review. As his career progressed, these basic technologies didn't change much. The quality of the video footage got better, and the number of cameras increased. Television broadcasts of his college games at the University of Southern California provided multiple cameras, which made it possible to review plays from different angles closer to the field. This also introduced some problems: the accumulating amount of footage, still captured in analog format, made finding a particular play to review a laborious process. Palmer still recalls with frustration the days of ana-

log Betacam tapes. “If you wanted to find first down, or red zone, or first and ten,” he told me, “you would have to go through these stacks . . . there was no categorizing it digitally like there is now. Now you just type in what you want and ‘boom,’ there it is. That was a huge, huge jump.”

I spoke with Palmer at the end of the Cardinals’ June 2016 minicamp. It was a few months after the most successful season in his career, during which he led Arizona to the NFC Championship game and the best record in franchise history. As a scientist studying virtual reality and a cofounder of STRIVR, the company that designed the VR system he was using, I wanted to know more about his experience with virtual reality, and why he felt it made him a better player. I’d gathered he was enthusiastic from the comments he’d made in a couple of articles published during the previous season that had become particularly popular around the STRIVR offices.<sup>3</sup> “It’s blown me away,” he told a writer for ESPN. “Literally six days a week I use it. . . . It’s been a big part of my prep every week.”<sup>4</sup>

I asked Palmer how VR compared with the other types of technology he’d used in his career. He described previous technologies—playbooks, tablet computers, even game film—as “prehistoric.” “It’s so much more beneficial than looking at film of someone else do it,” he told me, “or a diagram or an overhead projector. . . . It’s definitely helped in my preparation. . . . helped me absorb very complex systems, faster. I definitely got more reps.”

“Experience,” he added, “goes a long, long way.”

## HOW VR WORKS

The physical world changes when we move. Walk closer to a tree, and it gets bigger. Turn your ear toward a TV set, and it gets louder.

Touch your finger to a wall, and your finger feels resistance when it makes contact. For every physical action, there is an appropriate update to our senses. This is how humans have avoided bears, found mates, and navigated the world for millennia.

When virtual reality works well, it is seamless, and the virtual world changes just as the physical world does. There are no interfaces, no gadgets, no pixels. One second you are strapping on an HMD and the next you are somewhere else. That sensation of “being there,” wherever the program you are running takes you, is what researchers call *psychological presence*, and it is the fundamental characteristic of VR. When it happens, your motor and perceptual systems interact with the virtual world in a manner similar to how they do in the physical world. Carson Palmer internalizes his playbook faster in VR than with video because of presence. Presence is the sine qua non of VR.

Let me give you an example of presence in action. In 2015, we did a shoot for a major network news program in my lab. The anchor, one of the regular hosts, put on the HMD and did about a dozen demos. All the while his crew filmed him from three separate camera angles. The demo that stands out from that day-long shoot was one we call “The Earthquake.” In it, the user stands on a virtual factory floor, surrounded by heavy wooden crates stacked up to the ceiling. Each one is about the size of a desk, and they are stacked—rather haphazardly and precariously—about 10 feet in front of you and behind you.

For those of you who have been in a major earthquake, you know this is bad news. The good news is that in this virtual factory there is a very sturdy steel table to your left, tall enough for the user to fit underneath. It’s the classic instantiation of “Drop and Cover,” and we built this demo for the chief of the San Mateo County Fire Department with the idea of saving lives by teaching the muscle

memory to survive an earthquake. Think of it as an earthquake survival simulator.

The network anchor put on the headset and looked around.

“Have you ever been in a quake before?” I asked.

He replied no, and I made sure he saw the table. “That is how you will save your life.”

I then hit the “Q” button on the keyboard, initiating the quake in the program. The floor of our lab, which is made of a very rigid metal and designed to carry vibrations, began to shake and bounce. A thunderous rumble blasted through the lab’s spatialized surround sound speaker system. We could see everything he was seeing through a monitor on the wall of the lab. In the virtual factory, the boxes started to sway and tilt, and it was very clear that the whole stack was coming down right on top of the anchor.

Few people can hide their reactions to this highly persuasive simulation—the heart rates of most people will speed up. Their hands will sweat. But for some people, the illusion is so powerful that their limbic system goes into overdrive. We call these people “high presence,” and for them, VR is an especially powerful medium.

This anchor clearly fit that description. The simulation to him was psychologically real. He did exactly what we were trying to teach—he dropped to his knees and dove under the virtual table, put his head on the floor and his hands over his head. He reacted appropriately—took the actions to save his life. And he was clearly visibly upset by the quake.

Then something unusual happened. In our simulation, the boxes are stacked in the same starting point for every demo, but we model physics such that the effects are probabilistic. In other words, for every different earthquake—and we have run thousands of people through this—there is a different pattern of falling

boxes. Sometimes they fall backward, sometimes forward, and the collisions and ricochets are unique every time. The anchor had an experience that I'd never seen before. I guess you could say he hit the jackpot. One of the boxes had the perfect trajectory and somehow bounced right under the table with him. There are only inches of clearance, but somehow it happened, and in his safe zone under the table one of the boxes came crashing into him.

He screamed, pounced to his feet and sprinted. In his virtual scene, he was sprinting to safety. In the physical world, he was running right at a wall. I managed to stop him before he collided, but it was a close one. At the outset of the experience, he had consciously known the simulation wasn't real, but in the moment, the illusion of presence took over. His brain reacted as if the box were a real danger. As far as his brain was concerned, the fake falling boxes could hurt him.

Matthew Lombard, a professor at Temple University who has been studying VR since the 1990s, defines presence as “the illusion of non-mediation.”<sup>5</sup> On the tech side, we labor intensely to increase tracking accuracy, reduce the latency of the system, and do all the other magic it takes to build great VR. But for the user it's just a crate careening at your head while you are cowered under a table.

## TRACKING, RENDERING, DISPLAY

Before we go further, you need to understand a few technical matters. In order to create presence, three technical elements have to be executed flawlessly: *tracking*, *rendering*, and *display*. One of the reasons consumer VR is possible at all is that the computing requirements to make these vital elements possible are only now inexpensive enough to sell to a large customer base. If any one of these elements is off, users can experience simulator sickness—

an unpleasant feeling that occurs when there is a lag between what your body tells you you should be experiencing, and what you actually see.

*Tracking* is the process of measuring body movements. In the earthquake demo, we were tracking body position in X, Y, Z space, and the subject's head rotation. In other words, if he walked forward a step (positive on Z), we measured that displacement in his body position. If he looked left (negative on yaw), we measured this rotation. We recently published what is called a meta-analysis—a study that combines the summary data from every paper we could find that has ever been published (and many that haven't) in an area. The meta-analysis was designed to understand the relationship to all of the features that make VR special—the affordances—and psychological presence. We wanted to understand what the relative benefits of technological immersion were on psychological engagement. We looked at about a dozen features, ranging from image resolution to display field of view to sound quality. Tracking was at the top of the list, and it ranked second among all of the cues with an effect size of 0.41, considered to be a “medium” effect by statisticians. Basically, this means that for every unit increase on the technology side of tracking there was a bigger increase in psychological presence compared to the other technological improvements.<sup>6</sup> In my lab, we take great pains to track accurately, quickly to avoid latency, and often at a high update rate. At talks, when describing virtual reality technology I often tell a joke. What are the five most important aspects of VR technology? The punch line: Tracking, Tracking, Tracking, Tracking, and Tracking. (I'll be here all week.)

*Rendering* is taking a 3D model, which is symbolic, mathematical information, and instantiating the proper sights, sounds, touch, and sometimes smell for the newly tracked location. When you look down at this book, you only see it from a very specific angle

and distance. If you turn your head slightly, that angle and distance changes. In VR, every time a movement is tracked, the digital information in the scene needs to be rendered appropriately for the new location. It's not possible to store every possible viewpoint in a complex scene, so instead the viewpoints are rendered on-the-fly. The news anchor, when he dove to the ground, saw a new version of the room at every frame—which in our system in 2015 was 75 times per second. At each frame, we knew his precise location, and drew the floor closer and closer to his head as he dove down. We also rendered the sounds to be louder as he moved closer to the floor, since that is where the rumble was coming from. In VR, just as in the physical world, the senses need to be updated seamlessly based on movement.

*Display* is the manner in which we replace the physical senses with digital information. Once we render the sights and sounds for the newly tracked location, they need to be delivered to the user. For sight, we use a headset that can show stereoscopic information. As this book comes out, the typical headsets show images that are about 1,200 by 1,000 pixels in each eye, and update at 90 frames per second. For sound, sometimes we use earphones, while sometimes we use external speakers to spatialize sound. For touch, the floor shakes, and sometimes we use so-called haptic devices (more on this later).

The adoption of VR technology by athletes is only the latest chapter in a long and varied history of using virtual systems for training. In 1929, Edwin Link, an American inventor and aviation enthusiast, created the Link trainer. In his patent application (one of nearly 30 Link would receive in his lifetime), the machine

was described as “a fuselage-like device with a cockpit and controls that produced the motions and sensations of flying.”<sup>7</sup> We now know it as the original flight simulator, and many see it as an early example of virtual reality. According to Link’s biography, it was inspired by the frustration he experienced when he took his first flying lesson. That lesson, in 1920, cost him \$50 (over \$600 today), and the instructor wouldn’t even let him touch the controls. One can see it from the instructor’s perspective—planes are expensive, and lives even more so. At the same time, we learn by doing, and Link was understandably eager to get his hands on the controls. It raised a vexing question: How could you teach someone a dangerous skill without putting them, and others, at risk?

In this problem, Link saw a business opportunity. It was the ’20s, and the United States was in the middle of a civil aviation craze, creating a great demand for flight instruction. To remove the deadly risk of having beginners take the controls of an airplane, he created a fuselage that would move in three dimensions powered by pneumatic bellows, providing feedback to the student who was moving the controls. It was a great success—so much so that the military acquired his company in 1934, and by the end of the decade the trainer had spread to 35 countries and had been used to train untold numbers of pilots. In 1958, Link estimated that two million pilots had been taught on the Link trainer, among them half a million military pilots during World War II.<sup>8</sup>

Innovations in audiovisual reproduction and computers brought about digital virtual reality technology in the ’60s, leading, in the decades that followed, to a host of virtual simulators for training specialists with difficult jobs, such as astronauts, soldiers, and surgeons. VR was adopted by these fields for the same reason that flight simulators became invaluable for training pilots. Mistakes are free in VR, and when the risks of on-the-job learning were

high, technology that prepared a pilot, or a surgeon, or a soldier for the life-and-death responsibilities of his profession without risk was a huge win.

The use of VR for training would continue to grow. In the late '80s and '90s, early VR pioneers like Skip Rizzo at the University of Southern California began work with VR to help with physical rehabilitation for people who had suffered from strokes and traumatic brain injuries, and to train people to use prosthetics. These and other systems were designed to motivate users and ease the tedium of repetitious rehab exercises through interactive experiences. Some even provided feedback based on patients' movements, which reduced the potential for error when performing exercises. Studies showed these experimental therapies to be extremely effective. While there was a wealth of research showing that VR training was useful in a variety of domains, in 2005 I realized there were very few studies that specifically compared VR to other training techniques. Given how expensive it is to set up a VR training system, many from industry wanted to know exactly what their money would be paying for in terms of a gain in training. I decided to take a closer look, and my colleagues and I ran a comparative study to see how VR matched up against the most popular medium for training: video.

It's easy now to forget how much audiovisual technology has revolutionized education, but imagine you lived in a time before film was invented, and you were trying to learn how to dance, or swing a tennis racket, or perform even the simplest physical action without someone to teach you. Instead you would have nothing to go on but a diagram, or perhaps written or verbal instructions. Anyone who has tried to perform a repair on their car from a manual will immediately understand the challenge. The advantages of filmed instruction would have been obvious at the invention of moving

pictures. So it's no surprise that educational films are as old as the medium of film itself. The aptly named Educational Pictures, for instance, a studio founded in 1915 in Hollywood, exclusively produced instructional films for a few years before it discovered it could make more money with comedic shorts.<sup>9</sup> As the century went on, instructional films flourished, enjoying even greater popularity with the US government. With the advent of inexpensive and portable recording technology on video in the late '70s, there was an explosion in instructional video.

Today, ubiquitous digital recording technologies found in inexpensive cameras and phones, along with many Internet distribution channels like YouTube, have made it possible for hundreds of millions of enthusiastic amateurs all over the globe to learn how to do things like paint, swing a golf club, fix a leaky faucet, or play "Stairway to Heaven" on the guitar. Learning this way isn't superior to good personal instruction, of course. You can interact with a real-life teacher, who can provide personalized feedback and motivation. But video instruction is considerably cheaper than hiring a personal trainer or tutor, and is vastly more detailed than previous forms of self-education.

For over a century, moving pictures represented the best medium for instruction in physical activities. And now here was VR, which could, by leveraging the power of presence, create the sensation that a virtual instructor was in the room right next to you. I wondered if the unique properties of VR could take this kind of learning one step further. And if so, how extensive were the benefits?

The activity we decided to study was the martial art of tai chi. The training forms of tai chi involve complicated, precise movements in three-dimensional space, but they were slow enough to capture by using the tracking technology that existed at the time. In the study, we split the participants into two groups, each of

whom learned three of the same tai chi moves from an instructor. In one condition, the instructor demonstrated the moves on video. The other group of participants watched the moves as they were performed by a 3D virtual instructor, whose form was projected stereoscopically onto a screen in front of the participants. (Because the experiment involved physical movement, we did not want the students learning from the virtual instructor to wear cumbersome HMDs.) After the lessons were complete, participants were asked to perform from memory the series of tai chi forms that they had learned, which were recorded and sent to two coders trained to evaluate tai chi moves. These experts graded the participants on their accuracy. The findings showed that the group in the VR condition performed with 25% greater accuracy than the video group.<sup>10</sup>

Even with the limitations of the rendering systems in 2005, we were able to demonstrate that immersion in VR improved the learning of physical movements over a two-dimensional video, and to quantify that gain. Our tai chi study showed great promise for virtual instruction in fields like choreography, work training, and physical therapy, among others, and convinced me that improvements in the technology would one day lead to VR training simulations that could tutor users in complicated athletic movements, providing feedback and interactive instruction. This was good to know, as I would periodically be queried about this when athletes and executives from professional sports teams came through on tours of the lab in the decade following this study. How, they would ask, can this technology be used for football? For basketball? For baseball? At the time, there were rudimentary VR training tools for golfing and pitching, but those were mostly demos not designed for expert performers. No one, as far as I know, had successfully brought VR technology to the world of professional athletics.

There were a few very good reasons this was the case. As I've

mentioned, until about 2014, head mounted displays and the computers required to run VR were still too expensive and difficult to use outside of research labs like mine. But that wasn't the only difficulty. Just making a virtual environment was time-consuming. A fully immersive football simulation, for instance, would require every detail, from the cones on the field to the folds in a jersey to the reflection off of a helmet, to be built up from scratch, one-by-one on limited budgets. Professional sports teams might have had the funds to make this kind of investment, but it would be too expensive and risky to implement an unproven sport-specific training technology in the already tight practice schedules of a professional team.

There were other difficulties: Who would code the scenarios for the teams? How would the virtual practices be designed? What about the technical hurdles? Creating effective computer simulations of a complex and dynamic experience like a football play would be extremely difficult, and the technology to capture video footage to work with VR didn't really exist. Sure, the research showed that using VR to improve the performance of high-level athletes was possible, even likely in the not too distant future. But using VR for athletic training was not something we were likely to see anytime soon. Like so many other VR applications already in use at corporate labs and research institutions like mine, the costs to bring them to a wider market were just too great.

In retrospect, I was being overly cautious in my forecasts on when the long-awaited emergence of viable consumer VR would actually come about. After studying VR for years, I was certain that someday virtual reality technology was going to eventually become mainstream, and was going to have a revolutionary effect on the way we communicate and learn. Still, few of us working in the field anticipated how quickly this day would arrive. But a perfect storm of tech-

nological advancements, economic forces, and the bold actions of a few entrepreneurs suddenly made that future, which once seemed decades away, arrive in a few short years. Cell phone manufacturers brought down the prices for screens. Lenses got cheaper. Computers got faster. People like Andy Beall at Worldviz created motion-tracking technology and design platforms that made the creation of virtual reality environments easier. Engineers like Mark Bolas came up with creative ways to make affordable hardware. Then, in 2012, backed by a hugely successful crowdfunding campaign, Oculus would begin manufacturing a prototype for the first high-end HMD that could be sold to a large consumer market.

After Facebook bought Oculus in March of 2014 for over \$2 billion, you could suddenly sense the growing realization in Silicon Valley that something real was finally happening in VR. By January 2015, our lab's state-of-the-art HMD, the one that cost more than some luxury cars, had been replaced by developer models of consumer HMDs like the Oculus Rift and the Vive. These were smaller and lighter, worked just as well, and cost 1/100 of what we had been using. Now hundreds of developers were starting to develop content for these devices. And it was around this time that I was reacquainted with a former student of mine named Derek Belch, who also saw in that moment an opportunity to combine his passion for sports with the entrepreneurial VR fever that was sweeping Silicon Valley.

I had first met Derek Belch in 2005, a few years before the tai chi study, when he was a student in my class "Virtual People." Derek was also a kicker for the Stanford football team. (He has a place in the school's football lore for kicking a game-winning extra point in

Stanford's upset win over number-one-ranked USC in 2007, when we were 42-point underdogs.) As an athlete, Derek was naturally curious about how VR could be used to improve on-field performance. I told him the same thing I had been telling others when the subject came up—that the technology just wasn't there yet. But that didn't stop us from brainstorming after class about how a VR training regimen might be designed, once it became possible.

Derek returned to the lab in 2013 as a Master's student in the Department of Communication focusing on VR, right as the VR boom was beginning. With the rapid improvements in VR hardware and the renewed interest from Silicon Valley, we agreed it was the right time to pursue the study of sports training. The technology, it seemed, was finally ready.

As the 2014 school year started, Derek and I would meet twice a week to talk over his thesis and how the technology could be best utilized for elite athletes. We imagined a practice simulator for football—a way for players to see formations and run through plays, so that they could learn the offense and refine their ability to read the intentions and tendencies of opposing defenses. Getting these kinds of reps is vital for high-level athletes, but running through plays for the quarterback's benefit takes up a lot of time, requires the participation of many teammates, and always carries with it the risk of injury during practice. A VR trainer could capture important plays that the player would want to review, and allow him to reexperience the practice of the play as much as he wanted.

One thing we immediately agreed on was that the immersive environment must be photorealistic. Most of the study environments we used in the lab were computer-generated, but this approach wouldn't work for sports training. An athlete must be especially attuned to the small details in the game. The slightest

movement of an opposing player, a subtle lean in one direction, can give important clues about his intention and the entire course of a play. Accomplished athletes are attuned to such movements, and it would be vital for the VR-immersed player to see them. While it was theoretically possible for details like that to be created via computer graphics, it was not practical, and would require the resources and budget of a Hollywood digital effects department to pull off. We definitely didn't have that. Finally, real footage would help create the sense of presence, the sensation of "being there" in the virtual space, that was crucial to the learning experience we were creating.

360 video is now a familiar technology. Today, most large companies use it in one form or another, and even the *New York Times* produces 360 video content regularly. But in 2014 it was a challenge to produce. Coordinating the position and timing of 6 GoPro cameras simultaneously was a complicated task, and mounting the system on a tripod that was appropriately sized to work on a football field was an endeavor full of pitfalls. But when it is done right, a 360 video allows a person to put on an HMD and seamlessly look around a scene—one that updates to every micro-movement of his head and has high image quality. It's an amazing tool for quickly creating a highly realistic experience.

That spring, Stanford's coach, David Shaw, gave us the green light to bring our rig onto his practice field, a coup given how valuable practice time is, and how loathe coaches are to have their tightly choreographed schedules interrupted. But eventually we were able to get onto the field, film some plays, and get the content to the point where we were ready for our make-or-break moment—the demonstration for Coach Shaw. I'll never forget that hot day in April when I made my way to Coach Shaw's office to give the decisive demo of the system. After a computer crash and some fiddling

with a wonky laptop straining under the processing requirements, I finally got it working. Coach put on the HMD and looked around as I ran him through a few plays. After about 45 seconds he took off the goggles and said, “Yes. That’s it.” Coach has a calm demeanor. Mike Bloomgren, the offensive coordinator, then bounced in, and after seeing the plays was hooting and hollering, dropping to his stance and yelling out calls.

That was the day I knew we had something.

The system was implemented for the 2014 season. It started with the inevitable technological hiccups. By late fall a firm training regimen had settled into place. Coaches would scout the defensive tendencies of upcoming opponents, and then Derek would film these scenarios in practice. After the film was stitched together into 360 video, Kevin Hogan would be able to run through practice plays as often as he liked, studying for the game in a much more intense way than he would by watching film or looking through playbooks.

Not long after a consistent VR training regimen for Hogan was implemented (using the headset for about 12 minutes before games), something remarkable happened. It is impossible to isolate any one factor to account for what happened to the Cardinals’ offense at the end of that season, or any change in performance on any team. There are too many factors that influence success—schedule strength, new teammates, the inevitable peaks and valleys of performance that affect all athletes. Consequently, our policy has been not to assign too much credit to VR or to portray it as a wonder machine. Nevertheless, the statistics from that inaugural season certainly got our attention. After VR, Hogan’s passing completion numbers went from 64% to 76%, and the team’s total offense improved from 24 points per game to 38 points per game during this same period. But the most incredible numbers

involved the success rate of scoring within the “red zone,” or the space between the 20-yard line and the goal line. Prior to incorporating VR into their preparation, the Cardinals scored 50% of the time they entered the red zone—a poor rate of success. In their last 27 trips to the red zone in 2014, that rate improved to 100%.<sup>11</sup> Was this a regression to the mean, or was the STRIVR system giving Hogan an edge in his ability to read the game and make quick decisions?

Coach Shaw noticed the difference in Hogan right away. “His decision-making was faster. Everything was quicker,” Shaw later said. “He saw things happening and could make those decisions and anticipate the ball coming out of his hands. . . . I’m not saying there is a 1-to-1 correlation, but it was along those lines. . . . We got him to think a little bit quicker. I think this virtual reality immersion and going through these plays helped him.”<sup>12</sup>

After the season ended Derek had a meeting with Coach Shaw to discuss his future with the team. Shaw urged him to develop the VR training program and start a company. “He said ‘get out of here,’” Derek would recall. “You’re a year ahead of everyone else. Go start a company.” Shaw then became an initial investor in the business that would become STRIVR. (I am also an investor and cofounder of the company.)

Armed with statistics from the Cardinals’ season and some scientific studies on VR learning he’d discovered during his Master’s research, Derek took the \$50,000 in initial investment money and traveled the country looking for customers. His goal for the first year was to find one team. But by the start of the 2014–2015 football season, he had signed up ten college teams and six NFL teams to multiyear contracts, including the Arizona Cardinals. It was an astonishing beginning and a great challenge. Suddenly Derek and the fledgling company were faced with the task of implement-

ing individualized training regimens designed for teams playing at the very highest levels of the game, with an extremely promising but still experimental technology. This involved scaling up the company quickly and providing on-location support for the teams that were trying to figure out how to capture 360 video and incorporate that VR footage into their game preparations. The time-consuming stitching process that combined camera views into one seamless image required additional staff. Derek also hired some employees versed in data analytics to help the company crunch the numbers to measure how the players were improving as they used VR.

As that first season went on, it quickly became apparent that some teams were implementing VR training more than others. A few franchises barely seemed to be using it at all—it was difficult to tell, as many players neglected to log the minutes they spent using the HMDs. But as the season went on, one player was quickly standing out as a super-user, showing a consistent and steady use of STRIVR footage in his game preparation. This was the Arizona Cardinals' quarterback Carson Palmer, who, having just come back from a season-ending knee injury the year before, was enjoying a career year.

Thirty-six years old and a seasoned veteran, Palmer didn't particularly care for the technological innovations that teams seemed to be experimenting with constantly. "I don't buy in to all the new technology," Palmer said in November of 2014. "I'm archaic. I thought, 'There is no way this can change the way I play quarterback. But I am all in on this.'"<sup>13</sup>

When the season came to an end, Palmer had led Arizona to the franchise's best record of 13–3 and put up career best numbers in passing yards, passing touchdowns, and quarterback rankings. The Cardinals would make it to the NFC Championship game.

## “THE WHOLE, BIG PICTURE”

What goes through the mind of a quarterback during those frenetic seconds after the ball is snapped to him in a game? I get a sense of this when I put on the STRIVR HMD and watch some of the demo footage taken at a Stanford practice a few seasons ago. It's a view only people who have played or coached at the highest levels of the game ever get a chance to see. When the program begins, I'm on a turf practice field on a bright, blue-skied day. There are white clouds in the distance. As I look left and right I see a row of five offensive linemen arrayed in front of me. I can see 11 defensive players beyond them, some right up on the line of scrimmage, others running around trying to confuse me and disrupt my reads. Everyone seems enormous and extremely close. There is a cadence and then the ball is snapped. What I immediately notice are the five massive linemen lunging toward me from only a few feet away. There is also a flurry of activity in my peripheral vision. Because this is practice there is little contact, but I'm still amazed by the speed and power of everyone around me. I think I see a receiver running downfield to the left of my field of view. And then, almost instantaneously it seems, the play is over and the screen fades to black.

For those who haven't spent thousands of hours playing the sport, the sequence seems like chaos, everything moving too quickly to make sense of. My untrained eye is unable to distinguish between important and unimportant details. I see clouds, red jerseys, the linemen and their movements, and the receiver in the corner of my field of view, but I don't know how to make sense of any of it. But a quarterback sees the events much differently.

Later, I asked Palmer how he can react to so much happening so quickly. “You don't notice little things,” he told me, “you notice

entire things. The whole, big picture. Without really focusing on little things. You're using your peripheral (vision) on the entire picture." Experts in perceptual learning call this process "chunking." It's how all the disparate parts of a complicated cognitive activity become one. For instance, when you first learn how to ride a bike, you are all over the place. You are thinking about your arm and your leg, and as you learn through experience and trial and error, you begin to only need to focus on a few things. And as it goes more smoothly it becomes a big chunk. Your brain has become more efficient at this task. Eventually, you are riding a bike without thinking about it, allowing you to turn your attention to the many other things you need to think about on a bike—like other cyclists or cars or potholes. Excellence is about attention and the allocation of resources.

The reason expert-level players like Carson Palmer can so efficiently process all this information is that they have amassed—through practice, study, and gameplay—so much experience that they are able to create and call upon extremely refined "mental representations" of what's happening around them on the field. This concept of mental representation in part comes from the research of K. Anders Ericsson, who has spent his career studying expert performers in a variety of domains, from those who excel at memorizing long strings of numbers, to chess players, to professional athletes in sports from rock climbing to soccer. Chess players, for instance, have played so many games they know which parts of the board need their attention and which ones don't. They can look at a chessboard and in a matter of seconds know what the correct move is. An amateur player will waste a lot of energy visualizing possible moves that an expert can dismiss right away.

Ericsson's research shows that mental representations are honed by deliberate practice, a particularly engaged form of learn-

ing that is distinguished by a motivated learner with well-defined goals, who gets feedback from his performance and has ample opportunities for repetition. Palmer's method for preparation, which involves quizzing himself as he goes through the plays, satisfies all these conditions. But perhaps most importantly, VR gives him access to unlimited repetitions. As he told me, "There is no other way to learn but to get the reps, to get the experience, [VR]'s just as close as you can get to another rep." It should come as no surprise that, as Ericsson has pointed out (at a time before immersive video systems like STRIVR), the most successful quarterbacks are "generally the ones who spend the most time in the film room, watching and analyzing the plays of their own team and their opponents." What's happening today is that the film room is becoming an immersive virtual space that bears more resemblance to the actual practice field than it does to two-dimensional images within a frame.<sup>14</sup>

Another advantage of VR is that, because users' brains are treating the experience they are having as psychologically real, they are physiologically aroused in a way that is similar to what occurs during real experience. The sights and sounds of the practice field, along with the sight of large linemen charging, heighten the emotional state of the player using the trainer, which improves learning. You're not sitting in a bucket of ice after the game, looking at an iPad; you are in there. This, perhaps, explains why VR also works so well as a visualization tool. There's a lot of literature showing that visualizing actions helps with performance. The mere act of thinking about an action, for instance, produces brain activity similar to what you'd see if the action were actually being performed. But that is only if the visualization is done the right way. The problem, of course, is that there is a high variability in how well people can visualize and put themselves in those situa-

tions. With VR, coaches and trainers can create visualizations for players.

Yet another reason VR works extremely well for learning is that it utilizes body movements. When you experience a VR simulation, you move your body as if you were experiencing an actual event in the real world. What makes VR different from using a computer is that you move your body naturally, as opposed to using a mouse and a keyboard. Hence, learners can leverage what psychologists call embodied cognition.

Embodied cognition argues that, while of course the mind is located in the brain, there are other organs in the body that influence cognition. Muscle movements and other sensory experience help us understand the world around us. When we think, the parts of the brain that are associated with body movements become activated. Consider a 2005 study on dancers.<sup>15</sup> Scientists studied two groups of professional dancers—experts in ballet and capoeira. Dancers watched some recorded dance moves of both styles while their brain activity was recorded in fMRI. When the dancers saw the dance moves from their own area of expertise, the “mirror system” of their brains became activated, while when they saw the dance moves from the other style, their brains did not activate as strongly. In other words, when they saw the moves that they had performed thousands of times over their lifetime, their brains activated as though they were performing those actions. So simply watching and thinking about dancing caused the dancer’s brain to activate as if she were doing the moves herself. The brain understands watching an event by visualizing motor movements.

This activation of the motor action part of the brain can actually predict learning. In a study published in 2008 in the *Proceedings of the National Academy of Sciences*, scholars from Carnegie Mellon University examined hockey players, hockey fans, and novices to

hockey. Hockey experts were better at understanding hockey moves than the novices, and this difference was accounted for by brain activation. In other words, the more brain activation in the higher-level motor areas that are associated with expertise from the viewer, the better he was at understanding the hockey moves. While these data are correlational, proponents of embodied cognition posit that by simulating an action in the brain, one can improve learning. The authors of the hockey study conclude that “The impact of athletic experience on comprehension is explained by greater involvement of brain regions that participate in higher-level action selection for those with hockey playing and watching experience.”<sup>16</sup>

The impact of sensorimotor simulation in the brain also applies to basic science learning. In a 2015 study on college students learning physics, some learners were given actual physical experience with torque and angular momentum by spinning bicycle wheels around, while others just watched the wheels spin. Students who experienced the forces associated with angular momentum did better on a subsequent quiz than students who only watched the spinning wheels. And similar to the hockey study, the increase in performance could be attributed to the activation of sensorimotor brain regions which were measured later on when students performed similar physics tasks. This study shows first that people learn better by doing than by watching, but also that those who learn best are simulating motor action in the brain.<sup>17</sup>

We are still in the very early stages of understanding how best to use VR to maximize performance, which makes the gains shown in the early data so impressive. Going forward, STRIVR and other systems like it will be able to collect and analyze the massive amounts of data gathered by players like Palmer, who has shown himself to be especially adept at teaching himself, and discover the best ways to implement the training.

## THE FUTURE OF VR TRAINING

STRIVR's success in sports training eventually got the attention of the corporate world. It turns out that all the things that make VR useful for training a quarterback—quick assessment of a scenario, improvement of decision-making in chaotic situations, and of course the ability to practice when the stakes are virtual instead of real—are also surprisingly effective at training employees. Walmart, the world's largest retailer, signed up with STRIVR to build an app to train their employees. In a Herculean effort, one of our executives read Walmart's entire training manual cover to cover and picked out the simulations that would be most conducive to using VR.

The first module we built was in the supermarket. For the deli counter manager, this means practice on handling multiple customers at once, and making sure that when there is a long line you don't ignore people while handling the current customer. For floor managers, this means quickly walking down an aisle to see if the rolls of plastic bags hanging over the aisles are fully stocked, or noticing that one of the customers is lingering a bit too long in one place (is she shoplifting?). I learned that if you stack the corn cobs too high on the shelf in a supermarket, the ventilation gets blocked and it is a violation of code. It's an easy thing to program into VR. Spotting this error may not be as glamorous as picking up a hidden blitz and then throwing the winning touchdown pass in a playoff game, but it's the kind of small efficiency that makes a difference. We conducted a pilot study in 30 training academies to ensure that people would actually use and enjoy the system (they did). It turns out they also learned better, as Walmart saw the difference in measured performance, and decided to scale up to all 200 of their training facilities.<sup>18</sup> Walmart is building a library in which the written

manual will come with a set of experiences to train on. The beauty from their perspective is that VR is magnitudes of order cheaper than setting up a physical training store that is stocked with food and customers. But price aside, it's also more consistent—every trainee gets exactly the same experience, on demand.

When you start to consider these varied and powerful ways that interactive and analytical elements can be embedded in immersive virtual environments, the possibilities for VR training become endless. Training for soldiers, pilots, drivers, surgeons, police officers, and other people who are doing dangerous jobs—these are just a few of the hundreds of applications being used. But there are countless ways VR can be used to improve the cognitive skills we use in everyday life. Negotiation, public speaking, carpentry, machine repair, dance, sports, musical instruction—almost any skill can conceivably be improved through virtual instruction. We will see these and applications not yet dreamed of in the coming years as the consumer market grows, the technology develops, and our understanding of how to best use VR effectively improves.

This is a truly exciting and revolutionary time for education. Already, the Internet and video technology have opened up new opportunities for learning, and VR is going to enhance this development. There is so much untapped and untrained potential in the world. We have been taught to think that high-level performers are imbued with natural gifts that lead inexorably to greatness. While it is true that certain people are gifted with extraordinary natural abilities, it is only when that potential is combined with hard work and the proper coaching that it thrives. How many individuals are not meeting their potential because they lack the access to good instruction and learning tools?

I wonder, sometimes, at how frequently expert performance in specialized skills is clustered within families. Take the Manning

family in football, which boasts three top NFL quarterbacks in only two generations, with one of them, Peyton Manning, rated among the very best to have ever played the game. It is clear that the Manning family is specially gifted with some of the natural qualities required to become a great NFL quarterback. But does that tell the whole story? Isn't it also likely, especially knowing how much success at that position depends on decision-making based on experience, that brothers Eli and Peyton benefited from growing up with a father who was also a professional quarterback, who could explain the nuances of the game to them and instruct them on the fundamentals of playing it from a very early age? What about all the kids who share similar physical and mental gifts with the Mannings, but who never reach that potential because they haven't had access to expert coaching?

For me the most exciting aspect of VR instruction is its potential to democratize learning and training. To be sure, it won't be as easy as uploading a kung fu program in a few seconds, like Neo does in *The Matrix*. Learning expert skills takes dedication and focus and lots and lots of practice. But it does mean that eventually everyone will have access to resources that, should they be willing to put in the work, can put them on the path to expert performance. There is more pressure than ever before for high performers in all domains, and for specialization and focusing at younger ages. It's a stubborn fact that those with access to special tutoring and instruction have a great advantage over those who do not. Just as access to online videos and instructional courses have opened up opportunities for learning, so will VR. It will take time, of course, before the HMDs and the content are inexpensive enough to be adopted by those who lack access to the kind of specialized instruction that is necessary to succeed in our increasingly competitive world, but when

one considers how quickly data phones and their many apps have become ubiquitous, that future may come sooner than we think.

Sometimes, we don't value experience enough. Imagine a world in which the best teachers in all fields, realized as interactive embodied agents, are ready to guide promising minds through the lessons and practice necessary to thrive. VR training could go a long way in opening up real opportunities to millions whose talents are not being used.