

Perfecting your Pitch

In search of the perfect baseball pitch and its training



ERIK van der GRAAFF

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PERFECTING YOUR PITCH

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Chapter 1

Introduction

General introduction

With an estimated 65 million practitioners worldwide, baseball and softball belong to the most practiced sports worldwide. Especially on the North-American continent, including the Caribbean, and in East Asia the sport is very popular. In contrast, the sport is relatively small in Europe (Figure 1), which is reflected in the level at which it is practiced in most European countries. On the European continent, however, the Netherlands is an exception, since their team, called 'team Kingdom of the Netherlands', reached the semi-finals of the professional WBC World Championships twice in a row and was the last IBAF World Champion in 2011. Although the Dutch take pride in their international success, the Dutch baseball competition stands in the shadow of the professional competitions in the USA, Korea and Japan, where millions of people are filling up large stadiums on a daily basis. Not only is the sport more popular, also much more games are played at the highest level. In the American league, the Major League Baseball (MLB), each team plays 162 games within a six-month time span. A regular baseball game consists of nine innings in which one or more pitchers per team throw on average a total of 150 pitches per game. Thus, there is a high demand for pitching and the pitcher plays a major part in the outcome of every game. To be successful, pitchers should be able to throw fast and accurate, as well as a manner that is unpredictable to the striker.



Figure 1 (left) Sold-out baseball stadium during the Tokyo derby between Swallow and Giants, (right) Regensburg Legionaere, one of the largest baseball stadiums of Europe during practice matches between the Dutch and German youth teams. [Photos by Erik van der Graaff]

Most top-level pitchers are able to throw a baseball at 90 mph (144 km/h) or more, while preserving a good level of accuracy. To throw that fast enormous amounts of stress are put on the body, especially on the shoulder and elbow. Due to the high amount of stress on the body during pitching, combined with the high workload for pitchers during the season, pitchers are at considerable risk for (throwing) injuries. Pitchers have a 34% higher incidence rate for injury than any other player on the field, irrespective of position (Posner et al., 2011). Injuries are not only harmful for the players themselves, but, since a lot of money is involved in professional baseball, also form a huge problem from a business point of view. It has been estimated that in 2015 USD 695 million of player salary was lost because injured players were unable to play (Conte et al., 2016). There is thus a clear need, and challenge, to train and coach pitchers in such a manner that they are able to throw a 90 mph fastball while remaining injury free. To facilitate insight into the requirements to accomplish this, it is necessary to gain a better understanding of the pitching motion or pitching technique, pitching injuries, as well as potentially effective methods to acquire fast and safe pitching.

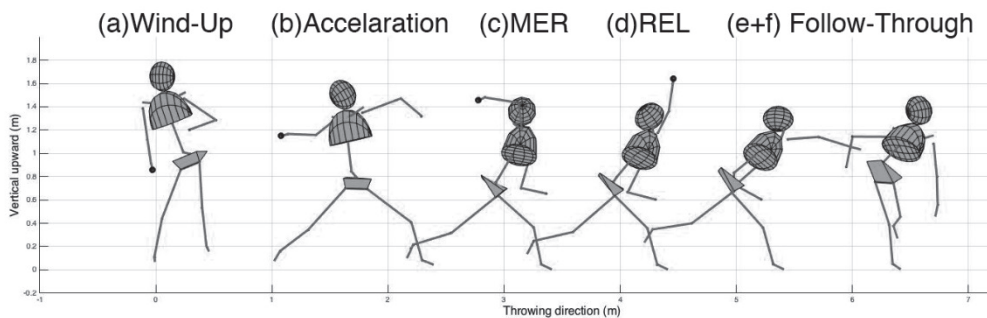


Figure 2 *The pitching motion captured in six figures. a) wind-up, b) acceleration, c) maximal external rotation of the shoulder (MER), d) ball release (REL), e+f) follow-through.*

The pitching motion

In all overhand-throwing sports, and especially in baseball pitching, the ability to realize high throwing speeds of up to 90-100 mph is seen as an extremely valuable asset. In baseball, many coaches and researchers have studied various aspects of the pitching motion, that is, a full body motion designed to throw a baseball as fast as possible. In one of the first papers published on the biomechanics of baseball pitching, 15 major league pitchers were studied using two synchronized 200 Hz cameras (Pappas et al., 1985). Three phases were distinguished in the description of the pitching motion: the cocking phase, the

acceleration phase and the follow-through. The cocking phase starts (for a right handed player) with the pitcher standing with his non-dominant (left) shoulder towards the catcher, facing third base. From this position, the pitcher starts the wind-up (Figure 2A). When a pitcher is making the step with his (left) front foot, the pelvis is translated in the throwing direction. After front foot contact (Figure 2B), the front foot side of the pelvis slows down considerably and becomes a pivot point (Seroyer et al., 2010). The translation and subsequent rotation in the transversal plane of the pelvis are employed together to initiate a rotation of the thorax (Robb et al., 2010; Stodden et al., 2001; Wight et al., 2004). The cocking phase ends when the shoulder is in maximal external rotation (MER, figure 2C). During the acceleration phase, the velocity of the ball is enhanced through a sequential rotation of body segments. The acceleration phase ends when the ball is released (REL, Figure 2D). The follow-through (Figure 2E+F) is the phase in which the arm and the body of the pitcher are decelerated after ball release. In this phase it is important to decelerate with a fluent motion in order to spread the stress of decelerating the high speeds over a longer trajectory.

Pitching and injuries

Unfortunately, throwing at high velocities is strongly associated with throwing injuries. Especially the throwing arm is prone to injuries. The dominant shoulder (31%) and elbow (26%) are the joints that figure most predominantly among baseball pitchers' injuries (Atwater, 1979; Conte et al., 2016; Fleisig et al., 1995; Hutchinson et al., 2003; Posner et al., 2011). Two common known injuries are the 'little league shoulder', which can be described as an inflammation or deformation of the proximal humeral epiphysis during the early growth of youth players (Atwater, 1979), and the 'Tommy-John' injury (Erickson et al., 2014), a tear of the ulnar collateral ligament (UCL) of the elbow. The latter injury is called after Tommy John, who was the first player to receive reconstructive surgery to his UCL in 1974. To prevent an epidemic growth of injuries, it has been suggested that training a proper throwing technique is required (Davis et al., 2009; Fleisig et al., 2009).

Throwing fast

The average fastball throwing velocity in the 2016 MLB regular season was 93 mph, a more than 3 mph increase compared to the 2002 season (MLB Statcast). In the 2017 season, one player, Aroldis Chapman, even averaged over 100 mph for the whole season. To throw at these high velocities, developing a good and safe throwing technique is essential. The question is, however, what a proper technique is for repeatedly throwing fastballs without becoming injured. In the past, a variety of studies have been published that examined the biomechanics of baseball pitching (Escamilla et al., 1998; Fleisig et al., 1995; Nissen et al., 2007; Pappas et al., 1985). A number of studies focussed on the



upper extremities (Aguinaldo et al., 2007; Stodden et al., 2006a), and some focussed on the use of the pelvis and lower extremities and their association with high throwing velocity (Milewski et al., 2012; Robb et al., 2010; Stodden et al., 2006a; Wight et al., 2004). All of the biomechanical studies in relation to baseball pitching investigated the following kinematic parameters: the maximal angular velocity of a joint (i.e. maximal velocity of axial rotation of the trunk), the range of motion of a joint during a specific period (i.e. knee flexion from foot contact to ball release), and the maximum range of motion of a specific joint (i.e. maximal external rotation of the shoulder). Some studies also measured kinetic parameters, although those studies mainly focussed on the association of those parameters with injury mechanisms (Davis et al., 2009; Fleisig et al., 1995). Several studies that focussed on the association of kinematic parameters with throwing velocity also investigated temporal parameters (Fleisig et al., 1999; Matsuo et al., 2001b; Stodden et al., 2005; Werner et al., 2008a). Pertinent temporal parameters are typically calculated in terms of the moment at which a percentage of the total pitch time has elapsed, where 0% corresponds to lead foot contact and 100% to ball release. For instance, Matsuo et al. (2001) compared such time-normalized parameters between groups throwing at different velocities. In the studies in question, a variety of individual kinematic and temporal components were found to be associated with throwing a fastball. However, none of these studies looked at the pitching movement as a whole, for instance by examining the interaction between segments in terms of inter-segmental timing.



Figure 3 The pitching motion involves two kinematic chains: the lower half of the body works as a closed chain translating the hip in the throwing direction, while the upper half of the body, from the left hip to the right hand, works as an open chain.

Inter-segmental timing

While the aforementioned studies aimed to investigate the role of individual joints or segments in reaching high throwing velocities, changing the characteristics of just one segment in a chain will disrupt the outcome of the system as a whole (Alexander, 1989). It appears therefore adamant to study pitching from the perspective of kinematic chains (Fradet et al., 2004; van den Tillaar et al., 2009) (Figure 3).

In an attempt to describe the total body contribution as a whole, rather than focussing on isolated kinematic parameters, or the duration of the throwing phases, some authors (Fradet et al., 2004; Herring et al., 1992; van den Tillaar et al., 2009) took the concept of the kinematic chain as a starting point. In a kinematic chain, segment velocities are increased and transferred from the proximal to the distal segments in the chain. However, it is not fully understood how this mechanism relates to creating high throwing velocities in pitching, even though it is most likely the main contributor in creating a high end-point velocity. Therefore, how segmental (rotational) velocity is created and transferred through the body warrants further study. To study this serial-order problem further insight is required into the absolute time interval between segments, that is, inter-segmental timing. Inter-segmental timing can be defined as the timing of the instances at which the peak (rotational) velocities of the segments, as part of the sequential motion of segments in the kinematic chain, are observed during pitching. Studying the absolute values of inter-segmental timing may provide a better understanding of the power-flow through the body. The power-flow provides detailed information about the source, production and consumption of segmental power from one segment to the next. Understanding the power-flow could also be worthwhile from the point of view of injury prevention. It can be argued that maximum loads should be distributed over the whole body in such a way that it does not damage the weakest link in the chain. Optimizing the working of the kinematic chain and the power-flow through the chain could help to distribute the load between the segments over the entire body, and thereby avoid overload of body structures during the pitching motion. It may well be possible that the aforementioned incidence of shoulder and elbow problems is partly caused by irregularities during step and trunk actions, that is, during the onset of the chain. It may be argued, therefore, that shoulder and elbow problems during pitching can only be resolved if, during training, instruction and feedback are provided about the whole kinematic chain. Eventually, understanding the inter-segmental timing can improve our understanding of throwing the perfect pitch, acknowledging the system as a whole, without the risk of overloading a particular segment or segments. Training the kinematic chain, therefore, might call for new ways of training involving forms of instruction and feedback that pertain to the body action as a whole.



Motor learning

Through understanding the kinematic chains of pitching essential elements of training and practice may be identified, which may aid (young) pitchers to learn to pitch fast and safe, or at least faster and safer. An important question in the context of skill acquisition is what types of instruction and feedback should be given to young talented pitchers to improve their pitching technique and through this, their throwing velocity. Previous research has suggested that instruction and feedback determine the focus of attention adopted by players, which in turn is known to affect both performance and learning. In particular, a distinction has been made between instructions with an external focus of attention, in which attention is focused on the effects of the movement in the environment, and an internal focus of attention, in which attention is focused on the movement itself (Wulf, 2007; Wulf et al., 2001c). It has been suggested that an external focus promotes automaticity in movement control, thus enhancing the effectiveness and efficiency of motor performance and motor learning (Wulf et al., 1998a; Wulf et al., 2001a). Many studies have found empirical support for these suggestions. A systematic review of the existing focus-of-attention literature was performed of the studies published to date in which a sports or a sports-like task was used. Thirty-three studies were found eligible and included in this systematic review. A short overview of the methods and main conclusions of the studies in question is provided in table X1.

The work reported in the present thesis focuses on the role of attention in developing the ability to pitch at high velocities. This choice is motivated from the fact that in baseball training plenty opportunities exist to give feedback and instructions about the effect of the movement in the environment. For instance, throwing the ball through the strike area of the batsman into the glove of the catcher can be readily translated into external focus of attention instructions, for example by instructing the pitcher to focus on the batsman's strike area or the catcher's glove. Pitching may thus be a suitable action to study the effect of instructions invoking either an internal or an external focus of attention in daily (baseball) practice. The question therefore arises if instructions invoking an external focus of attention are common in baseball pitching training, and, if so, if these types of instruction are helpful in pitching practice.

From the review of the literature (see Table X1) it is evident that within a broad range of tasks, from balancing and running tasks to throwing and soccer dribbling tasks, performance increased under external focus of attention conditions compared to internal focus of attention conditions. In a large portion of the studies included in the review of the pertinent literature, however, participants performed the activity in question only once, or for a limited duration on a single day; therefore, it may be concluded that those studies provide evidence about the direct effect of those types of instruction on performance ('performance studies', Table X1) but not on skill acquisition.

Some studies, in contrast, were performed over a somewhat longer period, and compared the acquisition of motor tasks over this period between interventions using either external focus or internal focus of attention conditions ('acquisition studies', Table X1). Although some of those papers concluded in favor of external focus conditions over internal focus of attention conditions for improved motor acquisition, the available evidence is mixed. It is also fair to conclude that, to date, the beneficial effects of an external focus of attention on skill acquisition have been mainly demonstrated in relatively inexperienced subjects, in sports-like situations with limited ecological validity, and in studies of relatively short duration. Before implementing external focus of attention instructions to improve the acquisition of the optimal throwing technique, there is thus also a clear need to compare the effectiveness of an external focus of attention and an internal focus of attention over a longer time span in well-trained individuals in an actual training environment involving regular instructors.

Implementing feedback and instructions in baseball pitching

With a better understanding of pitching mechanics and effective forms of feedback and instruction, new technological tools may be developed and implemented in practice. To date, facilitating feedback and instructions during training is mostly based on years of experience and expert opinions of coaches and trainers. In the future, however, feedback of information about for example inter-segmental timing, may constitute an essential innovation, since such information is not available to the naked eye, certainly not for less experienced trainers and players themselves. To enhance the quality of baseball pitch training, modern technology in pitching practice can provide trainers and players with useful and reliable information.

Providing feedback opens an option to exploit the natural synergy between biomechanics and motor learning. Previously, it has been established that feedback, in a broad sense, plays an important role in training practice (Lauber et al., 2014). However, to our knowledge, real-time technological feedback about the timing between segments has yet to be implemented in a training context and its effectiveness be investigated scientifically. Especially nowadays, thanks to the fast progression of the mobile phone industry, mobile measuring devices have become smaller, faster, and cheaper, and have become a normal part of our daily lives. Inertial Measurement Units (IMU's) have been developed to such a level that they can accurately measure linear and rotational accelerations of individual body segments during the pitching motion (Li et al., 2016), even though off-the-shelf systems are not yet capable of capturing the high arm velocities that are reached in high-level pitching. These IMU's can be used to facilitate (near) real-time feedback of pitchers' movement behavior during practice. These developments should be implemented in pitching practice to pitchers with information about the optimal pitching movement.



In addition, feedback from multiple sensors can be combined to provide information not only about single segments or joints, but also about inter-segmental timing. Studying motor performance and acquisition during practice with real-time feedback of IMU's allows measurement in a large volume and provides direct comparisons from pitch to pitch. This individualized feedback could complement the instructions from the coaches so as to achieve an even better throwing technique than with standard instructions and feedback. Since the present project aims to implement both instructions and feedback, it is questioned, whether or not combined with coaching instructions, to what extent feedback from wearables impacts training, and thereby supports coaches' instructions in their efforts to develop the perfect pitch.

Table X1 Summary of the study populations, tasks and designs of empirical studies on focus of attention in a sports (-like) context.

	<i>Number, age and experience of participants</i>	<i>Task and environment / Lab or field study</i>	<i>Number of trials / length of study</i>	<i>General result</i>
Performance studies				
(Beilock et al., 2002)	21 students, 19.9 SD 1.0 years, >2 years of experience, or handicap less than 8.	Golf putting on a carpeted indoor putting green.	20 trials in each condition.	Participants in the external focus condition performed better than participants in the internal focus condition and in a control group. Participants in the internal focus condition performed worse than the control group.
(Beilock et al., 2002)	20 students, 20.2 SD 1.9 years, novices (<2 years of experience) and experienced (>8 years of experience).	Soccer dribbling speed on indoor gymnasium-type surface.	1 trial with both feet in each condition.	Novices performed better in the external focus condition. Experts performed better in the internal focus condition with their dominant side, but better in the external focus condition with their non-dominant side.
(McNevin et al., 2002)	19 employees, 26-54 years of age,	Postural sway on force plate.	30s trial in each of condition.	No significant effect between external and internal focus conditions.

(Ford et al., 2005)	20 soccer players, 10 skilled 21.1 SD 1.37 years and 8 less-skilled 22.5 SD 3.98 years.	Soccer dribbling through slalom par-cours.	1 trial in each condition.	An internal focus of attention on the arms and feet interfered with performance in skilled performers. For less skilled performers, an internal, yet skill-relevant, focus of attention (foot) did not degrade performance.
(Zachry et al., 2005)	14 students, 26.2 years on average, >1 year experience.	Shooting accuracy in basketball with deflated ball, with EMG and VICON.	20 trials for both conditions.	Participants shot more accurate in the external focus condition than in the internal focus condition.
(Castaneda et al., 2007)	16 baseball players, 8 skilled 19.5 SD 0.5 years and 8 less-skilled 21.9 SD 0.9 years.	Baseball batting simulation.	40 trials for each condition and 40 control trials.	Different effects on performance for less and highly skilled athletes in adopting a specific focus.
(Schucker et al., 2009)	24 trained runners, 30.8 SD 8.9 years.	Running economy.	10 minutes running at 12 km/h per condition.	Increased running economy in the external focus condition.
(Porter et al., 2010a)	20 students, 21.2 SD 2.2 years, Amateur or non-athletes.	Agility L-run speed at hardwood surface in baseball gymnasium.	5 trials per condition.	Participants were faster in the external focus condition than in the internal focus condition.

<p>(Marchant et al., 2011)</p>	<p>17 experienced resistance trained male participants, 20.8 SD 1.4 years, >3 times a week.</p>	<p>Maximal repetition on 75% of 1-RM.</p>	<p>1 trial in each condition.</p>	<p>Participants were able to perform more repetitions in the external focus condition than in the control and internal focus condition.</p>
<p>(Marchant et al., 2011)</p>	<p>23 regular exercisers, 30.9 SD 12.3 years, >2 years of experience.</p>	<p>1-RM on assisted bench press.</p>	<p>1 trial in each condition.</p>	<p>Participants were able to perform more repetitions in the external focus condition than in the control and internal focus condition.</p>
<p>(Stoate et al., 2011)</p>	<p>30 expert swimmers, 17.5 SD 2.2 years, 10.2 years of experience</p>	<p>Swim 25m as fast possible.</p>	<p>1 trial in each condition.</p>	<p>Swimming times were similar between the external focus condition and control condition, but slower when the focus was internal.</p>
<p>(Zarghami et al., 2012)</p>	<p>20 students, 22.0 SD 1.6 years, somewhat familiar:</p>	<p>Discus throwing distance at university campus.</p>	<p>5 trials in each condition.</p>	<p>More effective performance during external focus condition.</p>

(Ille et al., 2013)	16 men, 20-30 years, novice (regional athletes, non-sprinters) and expert (regional and national competitions).	Sprint start time, indoors on synthetic track.	5 trials per condition.	Reaction and running times were faster in the external focus condition than in the internal focus condition.
(Makaruk, 2013)	30 national athletes 22.2 SD 22.4 years, no specific experience in throwing.	Over – and underhand shot put on an outdoor ring.	5 trials per condition each condition 2 days apart.	Throwing distance was larger in the external condition than in the internal condition.
(Abdollahipour et al., 2015)	24 gymnasts, 12.0 SD 2.1 years, experienced gymnasts.	Maximal vertical jump with 180-degree turn.	5 trials in each of the 3 conditions.	Superior movement execution and greater jump height in the external focus condition than in the control and internal focus condition.
(Porter et al., 2015)	84 students, 20.3 SD 1.7 years, low skilled.	20m indoor sprint time.	1 trial in each condition on separate days.	Faster movement in the external focus condition than in the control and internal focus condition.

(Schücker et al., 2015)	18 highly trained rowers, 20.5 SD 3.87 years.	Rowing on an ergometer in a lab.	8 minutes rowing per condition.	Internal focus led to performance decrements.
(Becker et al., 2015)	68 students, age 18-40 years, no previous training.	Standing maximal long jump.	5 trials. 4 groups in cross-sectional design	The external group jumped further than the internal group but was not different from the control group.
(Ducharme et al., 2016)	21 students, 21.3 SD 1.7 years.	Standing long-jump.	2 trials in both conditions.	Further jump distance and lower projection angle in the external focus condition than in the internal focus condition and baseline.
(Bezodis et al., 2017)	18 team-sport athletes, 22 SD 4 years, no specific experience.	10 meter sprint in an indoor lab.	3 trials per condition.	Sprint times in the control condition were faster than both the internal and external condition.
(Halperin et al., 2017)	8 intermediate and 7 expert boxers	Punching a boxing bag in the lab.	12 punches in each condition on 3 separate days.	Faster and quicker punches in the external focus condition than in the internal focus and control condition. Most tasks were performed faster and quicker in the control condition than in the internal focus condition.

Acquisition studies					
(Wulf et al., 2001b)	28 students, no age reported, no prior experience.	Balance on stabilometer.	7 practice trials on 2 days, 7 retention trials on day 3.	Participants adopting an external focus during retention were moving more effectively than participants adopting an internal focus.	
(Wulf et al., 2002)	52 soccer players, 18-25 years, 'some' experience.	Soccer kick accuracy on an astrotrurf pitch.	30 practice trials, after 1 week 10 retention trials	External-focus feedback resulted in greater accuracy than internal-focus feedback.	
(Wulf et al., 2002)	48 high school (novice) and university (advanced) students, 15-30 years, novices had no experience and advanced had some experience.	Volleyball serve accuracy and movement quality at physical education class (novices) and during training hours (advanced).	2x25 practice trials, 15 retention trials, all trials 1 week apart	The groups with external-focus feedback were overall more accurate than the groups with internal-focus feedback, independent of level of expertise	
(Totsika et al., 2003)	22 students, 19-36 year, no experience.	Riding speed on a pedalo 7m.	20 trials practice, 3 transfer conditions of 4 trials 1 day after practice.	External focus group had shorter movement times than the internal focus group.	
(Zentgraf et al., 2009)	58 students, 23.7 SD 2.54 years, no experience	Juggling	50 acquisition trials, 2 days later 20 retention trials	Juggling performance improved equally in all three groups.	

(Miçooğulları et al., 2012)	64 students, 14.1 SD 3.78 years, no experience.	Soccer 'head kick' in the school garden.	2 practice days with 12 trials a week apart, a retention day one week after.	All participants who said they used an external focus cue were better in kicking performance and learning than participants who used an internal focus cue.
(Pascua, 2013)	52 students, undergraduates, no experience.	Overhead throwing with non-dominant hand to target at 7.5m indoors in a racquetball court.	60 practice trials, next day: 10 retention and 10 transfer.	External focus condition practice resulted in greater accuracy than control condition practice.
(Chow, 2014)	16 adults, 18-25 years, physically active.	Running on a treadmill in a lab.	Pre-testing, then 6 training sessions in 3 weeks, 10 trials per session. Post testing one week after last training session.	Cycle time and stride length were not significantly different at post-test for participants in internal and external conditions.
(Lohse et al., 2014)	48 students, little to no prior experience	Darts throwing.	90 trials on day 1 and 2, 18 trials on day 3, with a day in between the practice days	Participants were more accurate when they focus externally than when focused internally.
(Woo et al., 2014)	13 participants, 30.7 SD 4.6 years, no prior experience.	Taekwondo sequence.	12 session of 30 minutes practice over 8 weeks. 3 retention trials after 1 week and after 1 month.	No significant differences between control and treatment groups in hand techniques, kicking techniques and 10-step routine. Individuals response differently towards the given instructions.

(Keller et al., 2015)	19 students, 27.5 SD 4.2 years, physically active.	CMJs in a controlled setting.	4 series of 8 jumps per condition.	An external focus resulted in greater jump height than an internal focus, and augmented feedback led to higher performance and better progression within one series than when adopting an external focus.
(Welling et al., 2016)	40 participants, 28 22.5 SD 1.62 years, physically active.	Landing after drop vertical jump.	2x10 practice trials, 5 pre- and post test trials, 5 retention trials after 1 week.	Females increased landing technique in both the video condition and external focus condition.

Note Performance studies examine the direct change in the outcome of a specific task or skill by changing one's focus of attention. Acquisition studies examine the change in outcome of a specific task or skill after training (post-test and retention) with different foci of attention.

Research context: project FASTBALL

This thesis is part of the STW funded research project 'FASTBALL' - Fast and Safe Throwing in Baseball - which aims to understand how young baseball pitchers can train, and be taught, to throw fast while avoiding injury. The project involves a collaboration between the Dutch baseball federation (KNBSB), the Vrije Universiteit Amsterdam and Delft University of Technology, as well as several external partners. The project is



unique in that all youth pitchers (12 – 18 years of age) of the six Dutch national academies participated in a three-year follow-up study, while pitchers of the national youth teams volunteered in a number of separate studies as well.

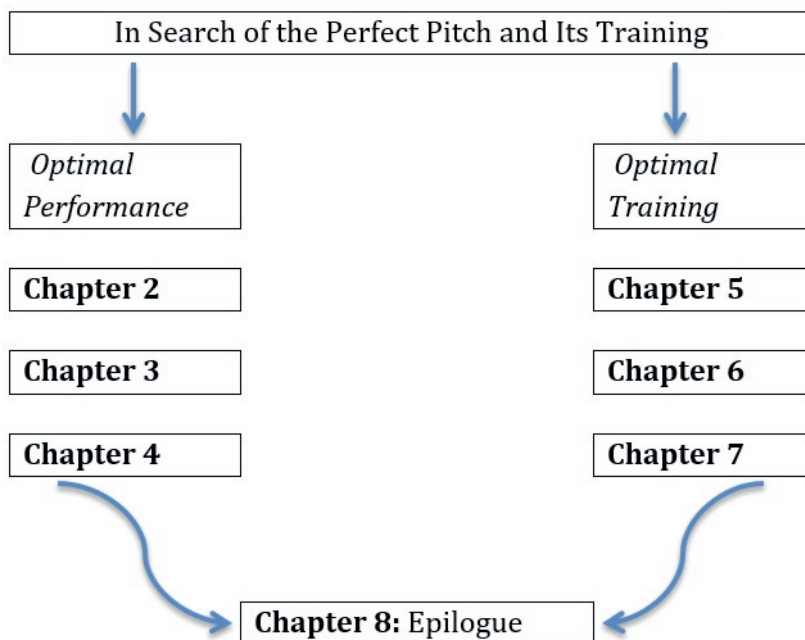
Within the research project there are two major lines of research. The first line of research consists of an in-depth examination of the optimal throwing technique and the most common injuries of pitchers. The second direction focuses on how this optimal throwing technique can be acquired. The project, and thus this thesis, is unique in that, in addition to theoretical findings, it aims for a high ecological validity by working closely together with coaches and trainers.

Main objectives of this thesis

The general aim of this thesis is to understand the optimal conditions for fast and safe throwing in baseball pitching and how to teach elite baseball pitchers to throw fast and safe in training. More specifically, the main objectives of the thesis can be summarized as follows:

1. To explore kinematic characteristics that focus on temporal (and kinematic) parameters of pitching in relation to (the development of) performance in elite youth baseball pitchers.
2. To determine and investigate methods for optimizing attention instructions in elite youth baseball pitchers
3. To investigate the effect of instructions and sensory feedback on performance in elite youth baseball pitchers.

Thesis outline



Optimal performance

To explore the characteristics of the pitching motion, **chapter 2** focuses on the role of the pelvis and the thorax during pitching. The main aim of this study was to quantify the relative timing between those segments, which involved an accurate definition of both thorax and pelvis rotation based on ISB-guidelines.

Chapter 3 complements this work by focusing on the role of the lower extremities. Characteristics of step length and the knee angle and their association with throwing velocity were studied in a group of youth pitchers of the Dutch national academies. Video analyses of the pitching motion were performed of pitchers throwing balls from either a pitching mound or flat ground.

The kinematic characteristics of the scapula are studied in **chapter 4**. The aim of this study was to compare asymmetry and the evolution of scapular upward rotation over a one-year period. The upward rotation of the scapula was studied in detail in order to gain insight into the possible development of scapula dyskinesia.

Optimal training

Chapter 5 presents an observational study that was performed to compare the prevalence of external focus of attention and internal focus of attention instructions given by experienced baseball coaches. Through recording verbal statements of the coaches of the Dutch national academies, during actual baseball practice, it was determined what type of instructions coaches used during practice.

To test the effectiveness of an intervention designed with external focus of attention instructions over a longer period in well-trained athletes, a five-week RCT cross-over study is presented in **chapter 6**. In this study the national youth teams of the Netherlands, Belgium, Germany and Italy partook not only as participant, but the coaches were actively recruited in the construction of the methods in order to ensure a high practical validity.

In **chapter 7** a study is presented in which pitchers received (near) real-time feedback about the rotations of their hips and trunk. In this study, not only the learning effects on the outcome measures were examined, but also the effect of feedback and instructions on the movement itself.

Epilogue

Finally, in **chapter 8**, the main results and conclusions of the previous chapters are summarized and highlighted. This summary is followed by a discussion of some limitations of the conducted research and practical implications of the presented results and possible directions for future research as well as practical recommendations for baseball coaches.



Part I



Chapter 2

The timing of peak pelvis and thorax rotation velocity in baseball pitching

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Abstract

The objective of the present study was to examine the magnitude and timing of peak pelvis and thorax rotations in achieving high throwing velocities in pitching fastballs. During the preseason (Test 1 or T1) and four months later (Test 2 or T2), kinematic analysis was performed on eight elite youth pitchers throwing fastballs. Peak rotation velocities of the pelvis and thorax were determined and separation time, defined as the time between the maximal rotation velocities of the pelvis and thorax, was calculated. Peak thorax rotation velocity was not associated with throwing velocity. However, separation time appeared to be significantly and positively associated with throwing velocity. Also, the changes in separation time from T1 to T2 were significantly and positively associated with the observed increase in throwing velocity from T1 to T2. There was no significant association between the changes in pelvis or thorax peak rotation velocities from T1 to T2 and the change in throwing velocity. Results indicate that the relative timing of pelvis and thorax peak rotation velocity in pitching fastballs in baseball is likely to be a determinant of throwing velocity in skilled pitchers.

Keywords: *throwing, motion analysis, kinematics, performance*



Introduction

In all overhand-throwing sports, particularly in baseball pitching, the ability to deliver high throwing speeds up to 100 mph is seen as an extremely valuable skill. The total body contributes to these high throwing velocities and has been described in different overhead throwing sports as the so-called 'kinematic chain' (Fradet et al., 2004; Putnam, 1993; van den Tillaar et al., 2009; Wagner et al., 2010). It is, therefore, not surprising that throwing velocity is associated with several kinematic parameters not limited to those of the shoulder and arm. The position, translation and rotation of the pelvis are also important contributing factors of throwing performance (Milewski et al., 2012; Stodden et al., 2005; Stodden et al., 2006a; Werner et al., 2008a; Wight et al., 2004). The translation and subsequent rotation in the transverse plane of the pelvis together are used to initiate the rotation of the upper body (Robb et al., 2010; Saitou et al., 2012; Stodden et al., 2001; Wight et al., 2004). Multiple studies demonstrated the role of upper body rotation velocity in baseball pitching (Matsuo et al., 2001b; Oliver et al., 2010; Stodden et al., 2005; Stodden et al., 2001; Werner et al., 2008a), and the subsequent characteristics of shoulder and arm movements (Dun et al., 2007; Escamilla et al., 1998; Gasparutto et al., 2016; Miyashita et al., 2008; Nakamizo et al., 2005; Nakamura et al., 2002). While these studies aimed to investigate the roles of individual segment rotations separately in reaching high throwing velocities, they did not report on the timing of rotations *between* those segments, which is an important aspect of the working mechanism of the kinematic chain. More specifically, understanding the timing between pelvis and upper body rotation could lead to a better understanding of the kinematic chain in baseball pitching. Although this can be studied by assessing the onsets of rotation of the pelvis and upper body, in relation to throwing velocity (in baseball) studies have been focusing on peak rotation velocities (Matsuo et al., 2001b; Oliver et al., 2010; Stodden et al., 2005; Stodden et al., 2001; Werner et al., 2008a), which are clearly an indication of the kinematic chain (Putnam, 1993).

The time interval between the peak rotation velocity of the pelvis and the peak rotation velocity of the thorax has been defined as separation or separation time (figure 1) (Sgroi et al., 2015; Urbin et al., 2013). It has been suggested that with an increase in the separation time, there is more eccentric loading on the thorax, which could result in a higher throwing velocity (Aguinaldo et al., 2007; Oyama et al., 2014; Stodden et al., 2006a; Wight et al., 2004). Based on video analysis, Sgroi et al. (Sgroi et al., 2015) reported a positive association between the separation of the hips and shoulders and throwing velocity. Urbin et al. (Urbin et al., 2013) reported in a between-subject study on variations in the timing of multiple segment in association with ball speed and upper extremity kinetic parameters. They demonstrated that increased time between peak angular velocities of the pelvis – defined as the line connecting the greater trochanters and upper torso – defined as the line connecting the acromion processes –

correlated with decreased ball speed. They also stated that variations in the duration of this phase are related to decreased ball speeds [p. 341]. In both studies, the movement of the shoulders was included in the approximated upper body rotation, thus upper body rotation was a combination of the movements of both the shoulder girdles and the thorax combined. To ascertain whether the findings on the timing of pelvis and upper body rotation in relation to ball speed in baseball pitching still hold with a more strict definition of the thorax segment, the present study focuses more closely on the timing of the peak rotation velocities of the pelvis and thorax, where the latter segment is defined based on recommendations of the International Society of Biomechanics (ISB), which implies the exclusion of shoulder motion (appendices 1&2) (Wu et al., 2005).

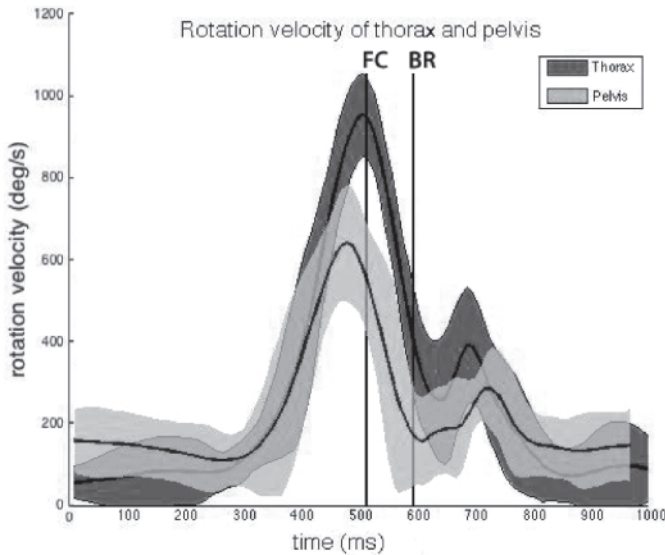


Figure 1 Average rotation velocity profile (black line) of thorax and pelvis from all pitches measured at T1, surrounding areas are ± 2 SD. Vertical lines are stride foot contact (FC) and ball release (BR). Rotation velocity profiles of different pitches are synchronized at peak rotation velocity

The objective of the present study was to investigate whether the separation time between pelvis and thorax peak rotation velocity is associated with throwing velocity in fastball pitching. It was hypothesized that separation time is positively associated with throwing velocity. Measurements were performed on the same young (16-18 years) individuals in the preseason and midseason. It was expected that throwing velocity increases in this time period



because of seasonal, training and growth effects. Therefore, additional –more convincing – evidence for an association between the separation time between pelvis and thorax peak rotation velocity and throwing velocity based on within-subject variation can thus be studied by exploring whether the *change* in the separation time between pelvis and thorax peak rotation velocity from preseason to midseason is associated with the *change* in throwing velocity.

Methods

Participants

Eight pitchers of the Dutch AAA team (age 16.1 ± 0.7 years, stature 181.7 ± 7.9 cm / $5'11'' \pm 3''$, bodyweight 76.9 ± 8.1 kg; mean \pm standard deviation) participated in this study. These elite young pitchers are the best pitchers of their age group in The Netherlands. After having been informed of the aims and procedures of the experiments, all players and, for those below the age of 16, their legal representatives, signed an informed consent form. The Human Movement Sciences' local ethical committee approved this research project under reference ECB 2013-53.

Procedures

Measurements were performed in the Adidas MiCoach Performance Centre in Amsterdam. A 10-camera (T40S, 100Hz) VICON (Vicon Motion Systems Ltd., UK) motion capturing system was used to record 3D marker positions. The cameras were installed around a portable mound to make the view as narrow as possible, optimizing the recording of all markers. Study aims and procedures were explained to the pitchers prior to being guided through a warm-up protocol. Pitchers performed a general warm-up of running and stretching, and a specific throwing warming-up, similar to a warm-up they would perform before a bullpen session. After the warm-up, retroreflective markers needed for 3D kinematic analysis were attached. The pitchers only wore tight shorts and indoor shoes so markers could be attached directly to the skin with double-sided tape. The markers were attached following the plug-in-gait model, with additional markers on the throwing arm (see Appendices 1 and 2). Pitchers were asked to perform at least five throws on the mound to get used to the setup and the attached markers. Pitchers threw towards a catcher, who sat in catching position at the regular game distance (18.4 m). Subsequently, pitchers were asked to perform five fastball pitches. The study consisted of two recording sessions; the first session (T1) took place in February 2012 before spring training. The second session (T2) took place 19 weeks later in the first week of summer break. During this 19-week period players followed the regular training schedule of the national U-18 team, which consisted of 4 training sessions per week, and from half April onward, also two matches per week.

Data analysis

Position data of the markers were exported from VICON and all calculations were performed in MATLAB (MathWorks, Natick, Massachusetts, USA). Pitches that were performed when markers came loose, or when a participant slipped from the mound, or did not hit the catchers' mitt, were excluded. If more than three pitches remained, the first and last pitch of the five was excluded to get three pitches for further processing. Before processing, landmark coordinates were splined with the standard MATLAB cubic spline interpolation function for missing data and filtered with a 4th order low-pass recursive filter at 12.5 Hz to reduce the effects of sampling error. Segment local coordinate systems (LCS) were defined for the thorax and pelvis with the markers attached as recommended by ISB (Appendices 1 and 2) (Wu et al., 2005), the axes were defined with the x-axis in the throwing direction, the y-axis from right to left and the z-axis pointing upward (Appendix 3). Segment angular velocities were directly calculated from the rotation matrices following Zatsiorski (Zatsiorski, 1998) (Eq. 1);

$$\dot{\omega} = 0.5 * ((R' \times R') - (R \times R')), \omega = [(\dot{\omega}(3,2); \dot{\omega}(1,3); \dot{\omega}(2,1))] \quad (\text{Eq. 1})$$

R = the rotation matrix expressing the orientation of the segment relative to a global coordinate system. \dot{R} = the numerical derivative of rotation matrix R. R' = transposed rotation matrix. the 3 × 3 skew-symmetric matrix containing the three angular velocity components around the three main axes. $\dot{\omega}$ = 3 × 1 rotation velocity vector [x,y,z]'.
 The magnitude of the angular velocity was calculated as the norm of the angular velocity vector (Eq 2.):

$$\omega_{\text{total}} = [\omega(3,2)^2 + \omega(1,3)^2 + \omega(2,1)^2]^{0.5} \quad (\text{Eq. 2})$$

A 2nd order polynomial function ($y=a+bx+cx^2$) was fitted using 11 measured data points that consisted of 5 data points before and after peak angular velocity in order to obtain the functions' coefficients *a*, *b* and *c*. Based on these coefficients the true moment in time of peak angular velocity (Eq. 3) and magnitude of peak angular velocity (Eq. 4) were analytically determined:

$$x = -b / 2a \quad (\text{Eq. 3})$$

$$y = a + bx + cx^2 \quad (\text{Eq. 4})$$

Throwing velocity was calculated as the peak linear velocity of a marker attached to the tip of the middle finger of the throwing hand in the direction of the throw, therefore the calculated velocity will be reported as 'fingertip velocity'.



Statistical analysis

First, the change of pelvis and thorax peak rotation velocity, separation time between pelvis and thorax maximal rotation velocity and fingertip velocity between the preseason (T1) and midseason (T2) were explored with simple linear regression analysis using GEE (Generalized Estimating Equations (Liang et al., 1993b) in SPSS (v 21.0.0.1, IBM Corporation, Armonk, NY, USA). The general simple linear regression equation was:

$$\text{outcome} = b_0 + b_1 * \text{predictor} \quad (\text{Eq. 5})$$

GEE was used, as it is able to account for the dependency between the repeated throws within pitchers. An exchangeable working correlation matrix was used. In the GEE analysis, participants were incorporated as a random factor to account for the dependency of the repeated trials within participants. Three fastball pitches per pitcher per recording session were used for the statistical analysis. Test 1 or Test 2 (T1 or T2) was entered into the regression model as categorical predictor variable (factor), while pelvis and thorax peak rotation velocity, separation between pelvis and thorax maximal rotation velocity and fingertip velocity were the continuous dependent variables. Regression coefficients (b_1) and corresponding 95% confidence intervals (CI) were determined and statistically tested using Wald chi-square statistics.

Whether pelvis and thorax peak rotation velocity and separation time between pelvis and thorax maximal rotation velocity were associated with fingertip velocity was also explored in a simple linear regression analysis using GEE. Pelvis and thorax peak rotation velocity and separation time were put in the regression model one by one as continuous predictor variables (covariates) while fingertip velocity was the continuous dependent variable. Thus, regression coefficients (b_1) and corresponding 95% CI were determined for each of the three predictor variables separately, i.e. pelvis and thorax peak rotation velocity and separation time. Data of both the preseason and midseason were pooled together in these analyses.

Comparable analyses were performed to investigate whether the change in pelvis and thorax peak rotation velocity and separation time between pelvis and thorax peak rotation velocity between the preseason (T1) and midseason (T2) measurements are associated with changes in fingertip velocity. Delta (change) scores were calculated by deducting the calculated values of every pitcher of T1 from the T2 values. The general simple linear regression equation was:

$$\Delta \text{outcome} = b_0 + b_1 * \Delta \text{predictor} \quad (\text{Eq. 6})$$

Table I Mean of throwing velocity, pelvis and thorax rotation velocity and separation for T1 and T2 and p-values.

	<i>T1</i>	<i>T2</i>	<i>p-value</i>
Throwing velocity (m/s)	30.0 ± 1.3	31.8 ± 1.4	<.001
Throwing velocity (mph)	67.1 ± 2.8	71.2 ± 3.2	<.001
Separation time (ms)	39 ± 9	34 ± 15	.293
Pelvis rotation velocity (°/s)	630 ± 68	661 ± 104	.129
z-component (axial rotation)	546 ± 77	616 ± 97	.004
x-component (lateral flexion)	170 ± 41	197 ± 82	.202
y-component (flexion/extension)	163 ± 64	181 ± 104	.307
Thorax rotation velocity (°/s)	975 ± 53	1014 ± 42	<.001
z-component (axial rotation)	825 ± 59	868 ± 89	.014
x-component (lateral flexion)	166 ± 73	179 ± 101	.878
y-component (flexion/extension)	450 ± 140	447 ± 189	.696

Note T1, preseason; T2, midseason; p-value is of the regression coefficient (b_1) for the difference between T1 and T2 as predictor of these outcome variables.

Results

The average fingertip velocity, operationalized as the linear velocity of the tip of the middle finger, was 30.0 ± 1.3 m/s (67.1 ± 2.8 mph) at T1 (Table 1). At T2, fingertip velocity was significantly higher compared to T1 by 1.8, 95% CI: 0.9 – 2.7 m/s (4.1, 95% CI: 2.1 – 6.0 mph). The average thorax peak rotation velocity at T1 was 975 ± 53 °/s. A significant increase was also observed in thorax peak rotation velocity, which was 39 °/s (95% CI: 21 – 58 °/s) higher at T2 compared to T1. On average, pelvis peak rotation velocity changed with 31 °/s (95% CI: - 9 – 73 °/s) and separation time with -5 ms (95% CI: -12.6 – 3.8 ms) from T1 to T2, but these findings were not significant: $p=.129$ and $p=.293$, respectively.

Separation time was significantly associated with fingertip velocity ($b_1 = 0.105$, 95% CI 0.072-0.138) (Table 2). Based on the resulting regression model, a 9.5 ms increase in separation time would result in 0.45 m/s (1 mph) increase in fingertip velocity. Pelvis peak rotation velocity was also significantly associated with fingertip velocity ($b_1 = 0.015$, 95% CI 0.001-0.030). Based on the resulting regression model, a 67 °/s increase in peak pelvis rotation velocity would result in 0.45 m/s (1 mph) increase in fingertip velocity. Within this group of young pitchers, thorax peak rotation velocity was not associated with fingertip velocity (Table 2, Figure 2).

The change in separation time from T1 to T2 was significantly and positively associated with the change in fingertip velocity with $b_1 = 0.238$ (95%



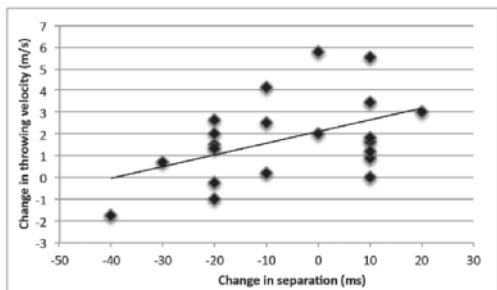
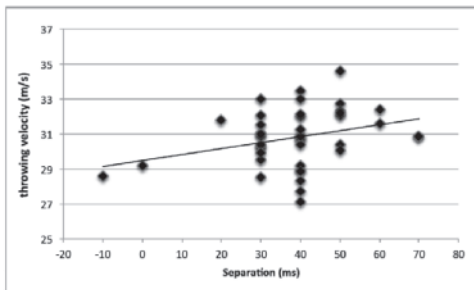
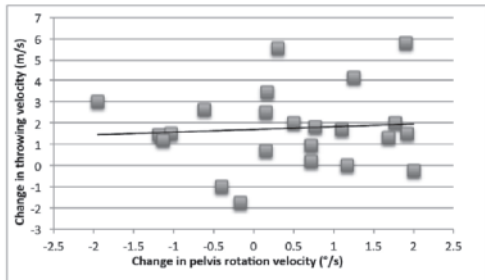
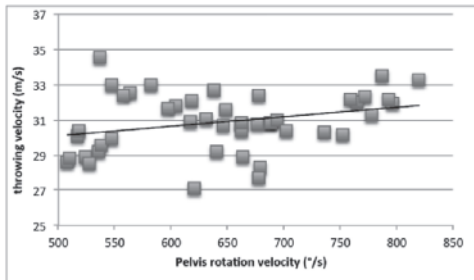
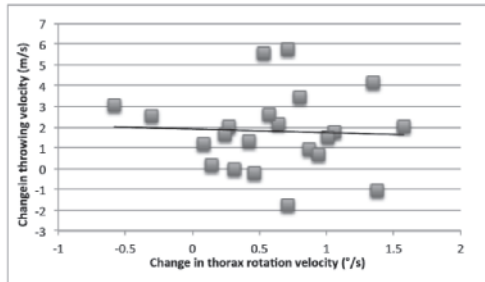
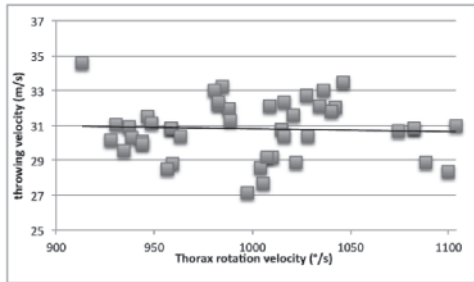
CI: 0.197 – 0.279) (Table 2). The regression coefficient indicates that a 4.2 ms increase in change in separation time would result in 0.45 m/s (1 mph) increase in change in fingertip velocity. The changes in pelvis and thorax peak rotation velocity from T1 to T2 were not associated with changes in fingertip velocity.

Table II Results of regression analyses (General Estimating Equations) concerning the associations of (changes in) pelvis and thorax peak rotation velocity and separation with (changes in) throwing velocity.

Throwing velocity = $b_0 + b_1 \times$ peak pelvis rotation velocity			
b_0	b_1	95 % CI b_1	p
59.128	0.015	0.001 – 0.030	.034
Throwing velocity = $b_0 + b_1 \times$ peak thorax rotation velocity			
b_0	b_1	95 % CI b_1	p
54.328	0.015	-0.022 – 0.51	.426
Throwing velocity = $b_0 + b_1 \times$ Separation			
b_0	b_1	95 % CI b_1	p
65.077	0.105	0.072-0.138	<.001
Throwing velocity = $b_0 + b_1 \times$ peak pelvis rotation velocity			
b_0	b_1	95 % CI b_1	p
3.784	0.013	-0.022 – 0.048	.454
Throwing velocity = $b_0 + b_1 \times$ peak thorax rotation velocity			
b_0	b_1	95 % CI b_1	p
4.532	-0.003	-0.50 – 0.043	.885
Throwing velocity = $b_0 + b_1 \times$ Separation			
b_0	b_1	95 % CI b_1	p
5.702	0.238	0.197 – 0.279	<.001

Note b_1 , regression coefficient; CI, the 95% confidence interval of b_1 .

Chapter 2



and separation (C) plotted against throwing velocity. Right column: Changes in thorax (D) and pelvis rotation velocity (E) and separation (F) plotted against changes in throwing velocity between T1 and T2. All graphs include trend lines based on the results of the regression analyses.



Discussion

In the studied sample of Dutch AAA pitchers, separation time between thorax and pelvis peak rotation velocity was positively associated with fingertip velocity in fastball pitching. We also observed a significant and positive association between the within-subject change in separation time and the within-subject change in fingertip velocity between the two measurements. This suggests that when peak rotation velocity of the thorax is observed later in time, compared to the peak rotation velocity of the pelvis, separation time increases fingertip velocity, resulting in an increase in throwing velocity. It should be kept in mind that there is likely to be an optimum for separation time and the predictions of the regression analyses should, thus, not be extrapolated outside the actual range of separation times that were observed in the present study (-10 to 60 ms).

This study underlines the reported positive association between throwing velocity and separation of the pelvis and upper body as shown by Sgroi et al. (Sgroi et al., 2015). While using video analyses, they demonstrated that pitchers who generally rotated the shoulders more than the pelvis showed the highest ball velocities. However, in contrast to the results of Sgroi et al. (Sgroi et al., 2015) and the present study, Urbin et al. (Urbin et al., 2013) discussed that an increased separation time is associated with a decreased throwing velocity, thus a negative association. The reported mean separation time of Urbin et al. (39 SD 19 ms) was comparable to the value in this study (39 SD 9 ms). Firstly, whereas the Urbin et al. (Urbin et al., 2013) study used between-subject variation, in the present study the association between separation time and throwing velocity was studied using both between- and within-subject variation. A positive association was observed between separation time and throwing velocity. This significant result was found using GEE that includes both between- and within-subject variation – because of repeated measures due to several trials on two occasions – in one analysis (Twisk, 2013). However, a positive association was also observed when we put more emphasis on the within-subject variation, this was done when we studied the changes from preseason to midseason. Secondly, in the present study, thorax rotation velocity was determined using markers attached to landmarks of the spine and the sternum, as recommended by ISB (Wu et al., 2005). Previous studies used markers on the left and right acromion; upper body rotation then would be a mixture of thorax rotation, scapular rotation and shoulder girdle protraction and retraction. As a result, the upper body, i.e. upper torso, peak rotation velocity estimated using acromion markers will be somewhat higher and the actual thorax peak rotation velocity will have a lower peak rotation velocity. Indeed, the observed thorax peak rotation velocity in the present study of 982 ± 51 °/s was slower than the peak rotation velocity of the upper body estimated using acromion markers reported in literature (1183 ± 109 °/s (Stodden et al., 2006a), 1227 ± 72 °/s (Matsuo et al., 2001b), 1190 ± 100 °/s (Fleisig et al., 1999)). This difference might affect the estimated

time of occurrence of thorax peak rotation velocity, and therefore, also affect the actual separation time. Considering the explorative nature of the present study, the relatively small sample size and the complexity of measuring the shoulder girdle, this issue of upper body or thorax rotation velocity in relation to marker placement warrants further study.

In the present sample of youth pitchers the association between pelvis rotation velocity and throwing velocity was significant and positive. The association between thorax peak rotation velocity throwing velocity, and the associations between the changes in pelvis and thorax peak rotation velocities from T1 to T2, and the change in throwing velocity from T1 to T2, were not significant. In line with these findings, Matsuo et al. (Matsuo et al., 2001b) found no association between maximum pelvis and thorax angular velocity and throwing velocity in a group of 127 college and professional baseball pitchers. However, it is reasonable to assume that the high rotation velocity of pelvis and thorax is a prerequisite for high throwing velocity, and differences in throwing velocity within a homogeneous group are likely based on technique differences. The effect of age and skill level on pelvis and thorax rotation velocity has been studied by Stodden et al. (Stodden et al., 2006a). They found an increase in pelvis and thorax rotation velocity between groups of varying age between 3 and 15 years. Furthermore, Fleisig et al. (Fleisig et al., 1999) compared pelvis and thorax rotation velocity between four age groups that all significantly differed in throwing velocity. Only the high school age group (15-20 years) showed a significantly lower upper torso rotation velocity and only the professional group (20-29 years) showed a higher pelvis rotation velocity than the other three groups. In these studies, with a cross-sectional design, it was demonstrated that age and skill level are positively associated with rotation velocity of the segments and throwing velocity. In the present study, the pitchers were part of a relatively small and homogeneous group and are the most talented pitchers of their age group (15-18 years. The average finger tip velocity of the elite youth pitchers in this study of 71.2 mph (31.8 m/s) is likely an underestimation of their actual ball velocity when pitching fastballs). They already showed high thorax rotation velocities and, not surprisingly, the inter-individual differences in rotation velocity between pitchers were relatively small. This might explain that no association between the maximal rotation velocities and throwing velocity was observed, whereas for separation time - as a measure of throwing technique - the association was positive and significant. Moreover, this association was also found within pitchers as we studied the changes from preseason to midseason. The association between the change in separation time and the change in throwing velocity, even within this small and homogeneous group, indicates that there could be a causal relationship between the two. This could be useful in, for instance, developing new training protocols for elite athletes to achieve higher throwing velocities.



Further studies, with respect to the role of the kinematic chain in pitching, should include other segments and their inter-segmental timing in the kinematic chain. To quantify the inter-segmental timing, especially of the upper extremities, it is recommended to use higher sample frequencies. In this study potential sampling issues were resolved using an analytical approach. Besides quantifying the inter-segmental timing of the kinematic chain, additional calculation of the power flow from segment to segment could give insight into the energy transfer between the segments. This energy transfer, for a tennis serve, was studied by Martin et al. (Martin et al., 2014) using a power-flow model. In baseball pitching, this model could give more insight in how the energy transfer is affected by separation time and this insight may result in higher throwing velocity. The importance of the separation time between pelvis and thorax, as observed in the present study, as well as between other segments in the kinematic chain, could initiate the development of new training protocols for achieving higher throwing velocities. Specific exercises and instructions could be developed to help train the sequential rotation of, for instance, the hips and thorax to achieve more, and ultimately optimal, separation time. As learning proper mechanics is also considered helpful in the prevention of injuries (Fleisig et al., 1995), a focus on the sequential rotations of segments according to the kinematic chain in learning fast pitching in baseball might also result in safer throwing.

Conclusion

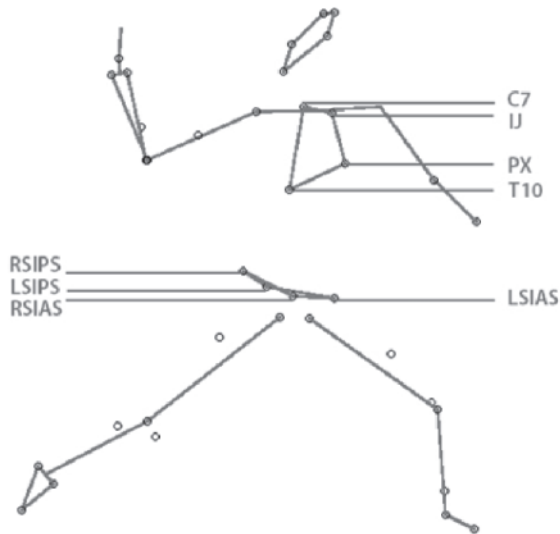
The relative timing of pelvis and thorax peak rotation velocity in pitching fastballs in baseball is likely to be associated with throwing velocity in elite youth baseball pitchers. Separation of segmental peak rotations deserves to be focused on in scientific research as well as in developing training protocols in baseball pitching.

Appendices

Appendix (1) Marker placement (See appendix (2) for figure).

Segment	Bony Landmark	
Pelvis (Right and Left)	Superior Iliac Anterior Spine	SIAS
	Superior Iliac Posterior Spine	SIPS
Thorax	Incisura Jugularis	IJ
	Processus Xiphoideus	PX
	Cervical Vertebrae 7	C7
	Thoracic Vertebrae 10	T10

Appendix (2) Placement of pelvis and thorax markers.



Appendix (3) *Markers used for calculation of local coordinate systems.*

Thorax	T10, C7, PX, IJ
x-axis	The line perpendicular to on y-axis and z-axis pointing forwards.
y-axis	The line perpendicular to the plane formed by IJ, C7, and the midpoint between PX and T8, pointing to the left.
z-axis	The line connecting the midpoint between PX and T10 and the midpoint between IJ and C7, pointing upward.
Pelvis	RSPIS, LSIPS, RSIAS, LSIAS
x-axis	midpoint of SIPS → midpoint of SIAS
y-axis	RSIAS → LSIAS
z-axis	Perpendicular on x and y



Chapter 3

Knee angle and stride length in association with ball speed in youth baseball pitchers

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Abstract

The purpose of this study was to determine whether stride length and knee angle of the leading leg at foot contact, at the instant of maximal external rotation of the shoulder, and at ball release are associated with ball speed in elite youth baseball pitchers. In this study, fifty-two elite youth baseball pitchers (mean age 15.2 SD (standard deviation) 1.7 years) pitched ten fastballs. Data were collected with three high-speed video cameras at a frequency of 240 Hz. Stride length and knee angle of the leading leg were calculated at foot contact, maximal external rotation, and ball release. The associations between these kinematic variables and ball speed were separately determined using generalized estimating equations. Stride length as percentage of body height and knee angle at foot contact were not significantly associated with ball speed. However, knee angles at maximal external rotation and ball release were significantly associated with ball speed. Ball speed increased by 0.45 m/s (1 mph) with an increase in knee extension of 18 degrees at maximal external rotation and 19.5 degrees at ball release. In conclusion, more knee extension of the leading leg at maximal external rotation and ball release is associated with higher ball speeds in elite youth baseball pitchers.

Keywords: kinematics; biomechanics; sports; fastball



Introduction

The throwing technique of a baseball fastball pitch can be described as a coordinated sequence of body movements and muscular forces with the ultimate goal of arriving at the highest ball speed possible at ball release (Calabrese, 2013). It is believed that the interaction of body segments transfers energy in a sequential pattern from the ground up to move the upper extremity joints into the right position to finally result in a high ball speed (Kibler, 1995; Steindler, 1955). The lower extremities and the trunk are the main force generators during initiation of the throw (Burkhart et al., 2003). For an optimal use of the trunk in force generation, the lower extremities have to be a stable base for the initiation of the rotations of the trunk and upper extremities throughout key phases of the baseball pitching action (Seroyer et al., 2010).

When the leading leg is extended it is braced to enhance the ability of the trunk to rotate both forward and in the axial direction simultaneously (Escamilla et al., 2002; Stodden et al., 2006a, 2006b). This braced leading leg was found to be associated with a high ball speed in pitchers (Elliot et al., 1988). A detailed analysis of lower limb mechanics was performed in a study by Milewski et al. (Milewski et al., 2012), although they did not investigate the relation between lower limb mechanics and ball speed. A commonly held view is that pitchers who flex their knee after the moment of stride foot contact (FC) are not throwing to their highest potential (Whiteley, 2007). This is supported by a study that reported pitchers who threw at a higher velocity had both a slower rate of knee flexion of the leading leg on landing and a higher rate of subsequent knee extension as compared with pitchers that throw at a lower velocity (Matsuo et al., 2001a). In addition to the knee angle at FC, greater knee extension of the leading leg was observed at ball release (BR) in faster throwing pitchers compared to slower throwing pitchers (32 SD 9° vs. 48 SD 14°) (Escamilla et al., 2002). Also, Werner et al. (2008b) reported this association between the knee angle of the leading leg at BR and ball speed ($\beta = -0.11$, SD -0.029 , $p = 0.009$). In the same study, however, a more flexed knee of the leading leg at FC was associated with a higher ball speed, which contrasts with most other studies.

Another lower extremity parameter of interest in baseball pitching is stride length, which partly is dependent on body height and the build of the pitcher (Elliott et al., 1986). A pitcher with a larger stride length results in more forward displacement, which can result in a higher ball speed (Ramsey et al., 2016; Ramsey et al., 2014). Furthermore, a larger stride length provides a greater moment arm for the trunk to rotate forward over the “locked leg”. Montgomery & Knudson (Montgomery et al., 2002) observed a positive linear relationship ($r = 0.73$) between stride length and ball speed in professional pitchers. However, this study was based on a small sample size and, to our knowledge, there are no other studies that relate stride length to ball speed, but

a study has been conducted that showed that ball velocity does not have to be affected with a smaller stride length (Crotin et al., 2014).

The studies described above indicate the importance of the lower extremities in achieving high ball velocities in baseball pitching (Milewski et al., 2012, Crotin et al., 2014, Kung et al., 2017). Quantifying the associations of several lower extremity parameters at several instants in the pitching cycle might give additional insight in how the kinematics of the lower extremities contribute to ball speed. However, the existing literature that associates lower extremity parameters to ball speed involves only adult pitchers (Elliot et al., 1988; Escamilla et al., 2002; Matsuo et al., 2001a; Montgomery et al., 2002; Werner et al., 2008b). Exploring the association between lower extremity parameters and ball speed in youth baseball pitchers might provide additional information as this study population shows more variance in anthropometric characteristics (segment lengths, force capacities) as well as in throwing technique and ball speed. The current baseball literature that includes youth baseball pitchers as participants is only descriptive without any associations with ball speed (Kung et al., 2017; Milewski et al., 2012). Therefore, the purpose of the present study was to determine whether stride length and knee angle of the leading leg at foot contact, at the instant of maximal external rotation of the shoulder (MER), and at ball release are associated with ball speed in elite youth baseball pitchers. It was hypothesized that a larger stride length, a more flexed knee at FC, and a more extended knee at MER and BR have a positive association with ball speed in elite youth baseball pitchers.

Materials and Methods

Participants

Data were collected from 52 baseball pitchers, with a mean age of 15.2 years (SD 1.7, range 10.4-18.5). Mean body height was 177.0 cm (SD 12.8, range 147.0-204.2) and mean body weight was 68.7 kg (SD 17.1, range 35.3-131.6). Of the 52 tested pitchers, 42 were right handed. Participants were recruited from the national youth baseball team as well as all (six) baseball academies in the Netherlands, at which the most talented baseball players of that region train. This research was conducted in accordance with the Declaration of Helsinki and the local ethical committee of the Department of Human Movement Sciences approved the measurement protocol. Both participants and their parents were informed of the procedure and study aims before the start of the measurements. Informed consent was obtained from the parents of the participants before involvement in the study.

Procedure

The measurements were performed at the indoor facilities of six baseball academies. After performing several anthropometric measurements, the



pitchers were given an unlimited amount of time to warm up for pitching. They were instructed to prepare just as if they were going to pitch in a game. The pitchers wore sneakers, athletic shorts and no shirt. They also wore their catching glove to mimic the game situation as closely as possible. Once a participant was ready to pitch, he performed ten fastball pitches for data collection. The participant pitched towards a catcher behind the home plate at a distance in accordance to the participants' age category (for players aged 13 years and younger the normal pitching distance [18.3 m] was changed to 16.5 m). Forty of the pitchers threw their pitches from a pitching mound. The other twelve pitchers threw from flat ground, because no indoor-mound was available during the measurements.

Data acquisition

Kinematic data were collected with three high-speed video cameras (XLZR 1000, Casio, Tokyo, Japan) at 240 Hz. The three cameras were placed approximately three metres from the pitcher to be able to film the entire pitcher from three different directions and to minimize projection errors (figure 1). The first camera was placed behind the mound and directed towards the home plate, the second was placed sideways to the mound and the third was placed slant in front of the mound. After the cameras were setup, they were not repositioned anymore as their image was calibrated using a wooden reference frame of 1.9 × 1.35 m (visible in figure 1D) to be able to perform 3D analyses. If one of the cameras was moved, a new calibration was performed. Before every pitch, a flashlight was used for synchronization of the video data of the three cameras. The ball speed (mph) reached during the pitches was measured from behind the home plate with a Stalker pro radar gun (Stalker Radar, Plano, TX).



Figure 1 The views of the three cameras for recording a pitch at ball release are shown. The red circles in picture A, B and C illustrate the five marked points in the view in question for the direct linear transformation. Picture D shows one of the three pictures of the wooden reference frame that was used for calibration.

Data analysis

Stride length and knee angles were calculated using Matlab (MathWorks, Natick, Massachusetts). Stride length was determined from the sagittal video, using a picture from the video at the moment of foot contact (FC). Foot contact was defined as the first moment that the heel, foot or toe of the leading leg made contact with the ground after the stride. Marking lines were taped on the ground at 1m, 1.5m and 2m, respectively, from the pitching rubber. The last marking line and the pitching rubber were marked manually in Matlab. The total number of pixels between those markings divided by the length of 2m was used to obtain the conversion rate. The stride length of the youth baseball pitchers was measured and defined as the distance between the pitching rubber and the ankle joint center of the leading leg at FC. Subsequently, the relative stride length was calculated as the stride length as a percentage of the participant's body height.

The images of the three video cameras were used to determine the 3D knee angle of the leading leg using the Direct Linear Transformation technique



(Shapiro, 1978). Synchronized pictures of all three cameras were calibrated with a wooden reference frame (visible in figure 1D), which was designed to include as much as possible of the space in which the pitcher was moving. The synchronized pictures of the three cameras were used to determine the 3D knee angle at the time of foot contact (FC), at maximal external rotation (MER) of the shoulder and at ball release (BR). For each of the three moments in the pitch cycle (i.e. FC, MER, BR), the corresponding three pictures of the three camera positions were used to mark five points in each frame: the joint center of the ankle, the midpoint of the shank, the joint center of the knee, the midpoint of the thigh, and the joint center of the hip (see figure 1C as an example). These points were marked manually using Matlab, without the assistance of markers attached to the pitcher's skin. A vector was fitted through the three points on each segment (upper leg and lower leg). Subsequently, the knee angle was calculated as the dot product of the two vectors. The knee angle was defined as the smallest angle between the vectors through the lower leg and the upper leg (Figure 2). A higher value for the knee angle thus means more knee flexion.

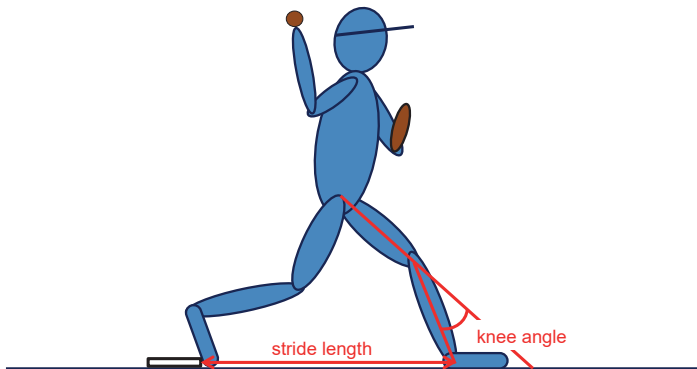


Figure 2 Illustration of the calculated stride length and knee angle calculated in 3D.

Statistical analysis

Five of the ten pitches of each participant were included in the data analysis. These five pitches consisted of the two fastest and the two slowest pitches, and one pitch that was closest to the pitcher's average ball speed. To explore the associations between the knee angles and ball speed, and between relative stride length and ball speed, regression analysis using Generalized Estimating Equations (GEE) was used (Liang et al., 1993a). GEE are a regression analysis that considers the five selected pitches of each participant as repeated

measurements and accounts for this dependency. This means that linear regression analyses could be performed without the necessity of using the average value of these five pitches. The advantage of this analysis is that within person variation is taken into account when calculating the regression coefficient. An exchangeable working correlation structure was used. Relative stride length and knee angles at FC, MER, and BR (independent variables) were analyzed separately in relation to ball speed (dependent variable). In these analyses the potential confounding variables body height, age, and body weight were taken into account, which showed a strong correlation with ball speed ($r > 0.8$). As all potential confounding variables appeared to be highly correlated with each other ($r > 0.75$), only body height was explored for confounding the associations to prevent collinearity, except for the analysis that included relative stride length, which was already expressed as a percentage of body height. Another potential confounding variable was pitching from a mound or flat ground since an independent-samples t-test showed that the ball speed of the mound group (30.6 m/s, SD 3.2) was significantly higher than the ball speed for the flat ground group (27.5 m/s, SD 3.4) ($t(50) = 2.9$, $p = 0.006$, Cohen's $d = 0.93$). This variable was not correlated with body height, so collinearity was not an issue. The analysis started with a simple linear regression with one of the knee angles or the stride length as predictor variable and ball speed as outcome variable. Then the possibly confounding variables body height and mound were separately added using multiple regression analysis. If the regression coefficient of the main predictor changed more than 10% when including the potentially confounding variable, this variable was considered a confounder (Kleinbaum et al., 1998). The interaction between the main predictor variable and the confounding variable was also checked. However, a significant interaction was never observed and interaction variables were, therefore, not included in the final GEE models. Standardized regression coefficients were determined as a measure of strength for the associations. All statistical analyses were performed with IBM SPSS Statistics 21.0 (IBM Corporation, Armonk, NY, USA) and a significance level of 5% was used.

Results

The mean ball speed observed for all 5 pitches of all participants was 67 mph (SD 8, range 48-82). The mean stride length of the participants was 140.8 cm (SD 15.2, range 99.8-173.8) and on average 79.8% (SD 6.0, range 62.4-92.8) of their body height. Results of the multiple linear regression analysis did not show a significant association between stride length as percentage of body height and ball speed (table 1; figure 3A).

The participants had a mean knee angle at FC of 40.3° (SD 14.6, range 10.9-94.6). Linear regression analysis with body height and mound as confounding variables showed that knee angle at FC was not significantly



associated with ball speed (table 1; figure 3B).

The mean knee angle at MER was 45.0° (SD 17.8, range 9.7-96.0). Body height and mound appeared to bias the association between knee angle at MER and ball speed. After adjusting for these confounders, knee angle at MER was significantly associated with ball speed (table 1; figure 3C). The negative regression coefficient found for knee angle at MER indicates that ball speed decreases as the knee angle increase, i.e. as the knee is more flexed. The value of the coefficient (-0.055) shows that youth baseball pitchers who have the knee of their leading leg 1/0.055°, or ~18°, more extended at the moment of MER throw 0.45 m/s (1 mph) faster.

The mean knee angle of the participants at BR was 40.5° (SD 19.0, range 3.9-94.7). The association between knee angle at BR and ball speed appeared to be biased by both body height and mound. After adjusting for these confounders, knee angle at BR was significantly associated with ball speed (table 1; figure 3D). Youth baseball pitchers throwing with a 1/0.051°, or ~19.5°, more extended knee at BR pitch threw 0.45 m/s (1 mph) faster.

Table 1 Crude and adjusted associations between lower extremity parameters and ball speed. Confounding variables with their regression coefficient (B) are presented when included in the regression model.

Kinematic parameters	with or without confounder	B	95% CI	Confounding Variables (B (95% CI))
Relative stride length (%)	Crude	0.046	(-0.082, 0.173)	-
	Adjusted	0.029	(-0.092, 0.150)	Mound (-6.447 (-11.339, -1.555))
Knee angle at FC (degrees)	Crude	0.023	(-0.012, 0.058)	-
	Adjusted	0.031	(-0.002, 0.063)	Body height (cm) (0.476 [0.401, 0.552]), Mound (yes/no) (2.345 (-0.989, 5.680))
Knee angle at MER (degrees)	Crude	-0.058 *	(-0.097, -0.019)	-
	Adjusted	-0.055 *	(-0.088, -0.022)	Body height (cm) (0.459 (0.384, 0.534)), Mound (yes/no) (1.235 (-1.909, 4.379))
Knee angle at BR (degrees)	Crude	-0.053 *	(-0.089, -0.017)	-
	Adjusted	-0.051 *	(-0.083, -0.019)	Body height (cm) (0.466 (0.391, 0.541)), Mound (yes/no) (1.231 (-1.912, 4.374))

Note (95% CI = 95% confidence interval) * $p < 0.01$.

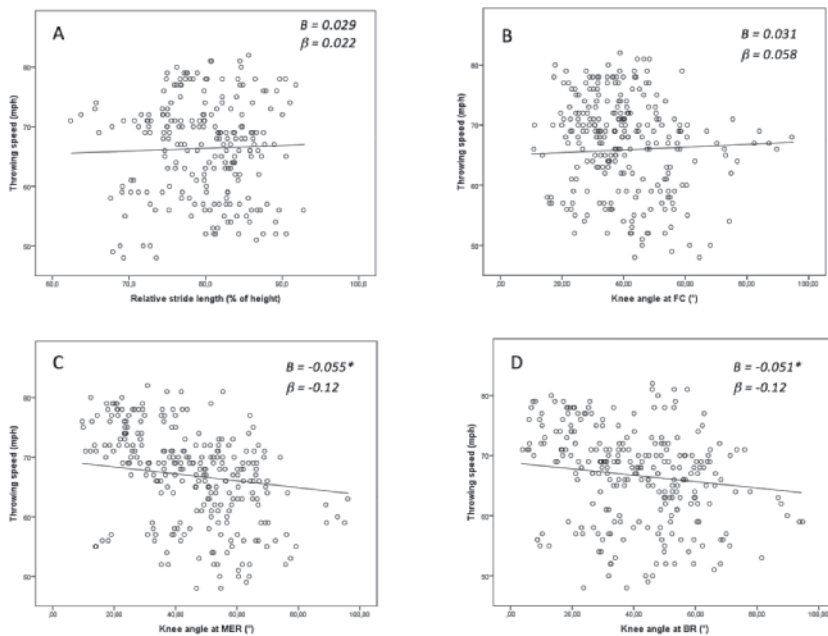


Figure 3 Scatter plots of observed values (including the repeated measures) of ball speed against stride length as percentage of body height (A), knee angle at foot contact (FC) (B), knee angle at maximal external rotation of the shoulder (MER) (C) and knee angle at ball release (BR) (D). Larger knee angles indicate greater flexion. Regression lines are according to the adjusted regression coefficients using Generalized Estimating Equations (GEE) (see Table 1). B is the unstandardized coefficient. β is the standardized coefficient beta * $p < 0.01$.

Discussion

The purpose of this study was to determine whether stride length and knee angle of the leading leg at FC, MER and BR were associated with ball speed in elite youth baseball pitchers. In support of our hypotheses knee extension at MER and BR appeared to be significantly and positively associated with higher ball speeds.

The increase in ball speed, which is associated with a more extended knee at MER and BR, was relatively small. To achieve an increase in ball speed of 0.45 m/s (1 mph) a more extended knee of 18-19.5° is required. However, although the effect seems to be small, it still appeared statistically significant in the population of the present study, which consisted of a homogenous group



of youth elite baseball pitchers. The observed result can be an indication of the relevance of knee angle. Moreover, the observed small effect may still be of practical relevance, because at the top level of baseball, small details can make a large difference.

Table 2 Comparison of kinematic parameters between the current study and the literature. For each study, if available, mean (SD) values are presented.

Parameters	Present study	Milewski et al. (2012)	Fleisig et al. (1999)	Dun et al. (2008)
Age group (years)	15.2 (SD 1.7)	12.4	-	12.5 (SD 1.7)
(Range)	(10.4-18.5)	(10.5-14.7)	(10-15)	(9.8-14.9)
Stride length (% height)	79.8 (SD 6.0)	69 (SD 6)	85 (SD 8)	70 (SD 5)
Knee angle at FC (°)	40.3 (SD 14.6)	49 (SD 12)	43 (SD 12)	49 (SD 8)
Knee angle at MER (°)	45.0 (SD 17.8)	46 (SD 15)	-	-
Knee angle at BR (°)	40.5 (SD 19.0)	41 (SD 16)	36 (SD 11)	31 (SD 9)

The average stride length in this study was 80% (SD 6) of body height; this is comparable to the stride length found in two other studies (Fleisig et al., 1999; Kageyama et al., 2015). However, a couple of other studies found different results (Dun et al., 2008; Milewski et al., 2012) (table 2). The latter studies defined stride length as the distance between the centers of the ankle joints and corrected this value for body height, while in the present study the distance between the pitching plate and the center of the ankle joint from the leading leg was defined as the stride length. Since most pitchers place the foot of their trailing leg in front of the pitching plate, the definition of these two studies results in lower relative stride length values. This should be taken into account for the comparison with the value of this study. The linear regression analysis showed no significant association between ball speed and stride length as percentage of body height in youth baseball pitchers. This association can only be applied to stride lengths within the range of 62-93%, because this study did not measure any stride lengths outside this range. Only Montgomery and Knudson (Montgomery et al., 2002) also examined the association between stride length and ball speed and demonstrated a significant association between stride length and ball speed. Pitchers in that study had to throw with their normal stride, with under-stride and with over-stride, which provided a similar range (75% - 100%, assuming a body height of 180 cm) as in the present study. However, this study is not comparable with the present study because the

association was determined for each pitcher individually, while in the present study associations were determined at group level. It might even be beneficial to have a shorter stride length, since it does not seem to affect ball speed, but it does reduce physical exertion (Crotin et al., 2014). Overall, more research is needed to understand whether there is an association between stride length and ball speed or not.

The knee angle of the leading leg starts with a mean flexion of 40.3° (SD 14.6) at FC and is followed by more flexion at the time of MER (45.0° SD 17.8). Subsequently, the knee extends towards BR (40.5° SD 19.0), which is consistent with previously published results (Escamilla et al., 1998). However, the knee angle at FC is smaller compared to other studies (Dun et al., 2008; Fleisig et al., 1999; Herring et al., 1992; Milewski et al., 2012) (table 2). There are two studies that measured the knee angle at MER in youth baseball pitchers (Kageyama et al., 2015; Milewski et al., 2012). They found a value of 46° (SD 15) and 39° (SD 12.1), which is comparable to the value found in this study (45.0° SD 17.8). The knee angle at BR is within the range of the values found in other studies (Fleisig et al., 1999; Kageyama et al., 2015; Milewski et al., 2012). We found a significant negative association between the knee angle at MER and BR with ball speed. This is similar to the study of Werner et al. (Werner et al., 2008b), in which a higher ball speed (1 mph) was found in pitchers with more knee extension (9°) in the later part of the pitch cycle (Werner et al., 2008b). According to these and our results, youth baseball pitchers should throw with a more extended knee of the leading leg. However, it is important to notice that the present cross-sectional study and the cross-sectional study of Werner et al. (2008b) only report associations between ball speed and knee angle, which do not support a causal relationship in which a more extended knee would lead to higher ball speeds. Therefore, practical implications based on these associations should be critically evaluated. In case of a potential causal relationship, it should be realized that knee extension is limited, which means that the gain in ball speed by more knee extension in the later part of the pitch cycle is limited. It should also be mentioned that at maximal extension, the knee is more vulnerable to injury (Fornalski et al., 2008).

The observed association between ball speed and the knee angle of the leading leg might actually be a causal relationship when several mechanical theories are taken into consideration. The extending knee results in a braced leading leg. This results in a braking effect during the stance phase, which means that the leading leg stops moving forward and the proximal segments rotate over the leading leg. The pitcher should not flex his knee from the moment of FC because this will result in energy dissipation because a non-moving and locked hip (i.e. a fixated trochanter major in space) requires less muscle power of the knee extensors with an extended knee compared to a flexed knee as a result of the shorter moment arm. The trunk is the segment with the highest mass and



is, therefore, potentially one of the greatest force generators in the kinetic chain (Burkhart et al., 2003). Also, in other sports like javelin throwing, the braking effect of the lead leg is shown to be important because it allows the trunk and upper extremities to accelerate forward over the leading leg, aiding the transfer of momentum up through the trunk and the throwing arm (Bartlett et al., 1996).

In the present study population of youth baseball pitchers, a large range of body types was present due to the obvious effects of growth and maturation at these ages (Malina et al., 2004; Malina et al., 2015). The effect of maturation was, however, not within the scope of the present study. If similar measurements would be performed over time, future studies could focus on the effects of growth in relation to throwing velocity. In the present study, however, we do have to correct for the observed range of body types to arrive at the independent association between the kinematic variables and ball speed. As explained in the methods section, we only treated body height as a confounder, as it was expected to largely affect ball speed. Body height itself was highly correlated with body weight, age, and strength ($r > 0.75$) (which were thus all strong predictors of ball speed [$r > 0.8$]). Taking all these confounders into account at the same time in the multiple regression analyses would have introduced issues of collinearity. Therefore, only one of those potential confounding factors needed to be selected for eliminating confounding. Of those factors, body height appeared to be the strongest predictor and was, therefore, the variable chosen for exploring confounding. One should bear in mind that body height should be considered a variable representing other variables like body weight, age etc., and not only an explanatory variable by itself. In the regression models it was observed that pitchers threw around 0.45 m/s (1 mph) faster for every increase in stature of 0.02 m. Another variable that was explored for confounding, and also interaction, was the mound. Pitchers who threw off a mound had a more extended knee at the moments of FC, MER and BR. Therefore, the mound was included as confounding variable. However, interactions with mound appeared not to be significant. This means that the associations between knee angle and ball speed, and between stride length and ball speed, are not different for the pitchers throwing from a mound and the pitchers not throwing from a mound. Others also reported kinematic differences between pitching off a mound compared to flat ground (Fleisig et al., 2011; Fleisig et al., 2017; Nissen et al., 2013). Nissen et al. (2013) reported that the knee of the leading leg was in more extension at FC when pitching off the mound. This probably occurs as a consequence of the delay in lead foot contact when stepping down off the mound (Nissen et al., 2013). Furthermore, ball speed was shown to be different when pitching from flat ground compared to pitching of a mound (Fleisig et al., 2017). This difference in ball speed highlights the importance of including the mound as a confounding variable. However, having included pitchers that also do not throw from a mound in the present study next to pitcher that do throw

from a mound, warrants careful generalisation of the results of the present study. In future studies, the associations between kinematic variables and ball speed should be examined, preferably when pitchers only throw from a mound, throw only on a flat ground, or do both.

Conclusions

In conclusion, while stride length and knee angle at FC are not associated with ball speed, more knee extension of the leading leg at MER and BR is associated with higher ball speed in the present sample of elite youth baseball pitchers. Whether pitching with more knee extension at MER and BR can be trained and whether this actually affects ball speed should be subject of future studies. In addition, future studies should focus on describing the knee angle during the complete pitching cycle and study whether certain characteristics of this time series, for instance the rate of change of the knee angle within a certain phase of the pitch cycle, are associated with ball speed.





Chapter 4

Asymmetry and evolution over a one-year period of the upward rotation of the scapula in youth baseball pitchers

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Abstract

In baseball pitching, the scapula plays an important role in the transfer of energy from torso to arm. As a result of the typically asymmetric training of the pitching motion, coordination of scapular rotation in the dominant arm might be affected in time and in comparison with the non-dominant arm in youth baseball pitchers. The aim of this study was to compare asymmetry and the evolution of scapular upward rotation over a one-year period. Data were collected twice over a time span of one year, from 92 participants (mean age=15.1 SD 1.4 years, mean body height =177.3 SD 10.9 cm, mean body weight 69.2 SD 14.5 kg). The trigonum spinae (SM), angulus acromialis (SL) and the angulus inferior (AI) of the scapula were palpated and marked with colored permanent marker on the skin and motion was tracked at different glenohumeral angles of elevation in the scapular plane: anatomical position (0°), 45°, 90° and 135°. Scapular upward rotation was calculated as the angle between the spinae scapula and the spine. On average, scapular upward rotation was 5.10° (95% CI: 2.07° -8.13°) greater for the dominant compared to the non-dominant arm. This difference was not affected by age group or glenohumeral angle of elevation. Over the one-year period a non-significant decrease of 1.88° (95% CI: -0.52° - 4.28°) in upward rotation for the dominant arm was observed, again in the absence of a significant interaction with either age group or elevation angle. These findings may indicate that youth baseball pitchers could be at risk to develop shoulder injuries, especially pitchers that have been associated with scapular asymmetry.

Keywords: pitching; baseball; overhead throwing; scapular upward rotation; scapular dyskinesis;



Introduction

When throwing overhead athletes solve a complex full body problem in order to generate high throwing velocities. Baseball (170 km/h), handball (130 km/h) and javelin (113 km/h) are all examples of sports that involve very high throwing velocities. Such high speeds can only be reached with a perfected technique that involves the entire body (Putnam, 1993, Matsuo et al., 2001). In the throwing action, the scapula plays an important role in controlling the shoulder joint. The scapula must move in accordance with the humerus to provide a stable base for the humeral head, but also plays an important role in the transfer of energy from torso to arm (Forthomme et al., 2008, Borsa et al., 2008). The available margins for healthy scapular motion are rather limited. The scapula provides congruence between the humeral head and the glenoid cavity to stabilise the glenohumeral joint (Borsa et al., 2003 & Kibler et al., 2010). In sum, scapular support is essential for stability and mobility during the throwing action in overhead throwing athletes.

It is often considered problematic when differences in the kinematics between the left and right scapula are found in athletes performing overhead throws, even though in many asymptomatic athletes such asymmetry exists (Oyama et al., 2008). Thomas et al. (2010) concluded that the asymmetric passive range of motion in combination with scapular dyskinesis may predispose to injury. Dyskinesis is defined as an asymmetric scapular movement due to physiological constraints in the shoulder girdle (Kibler et al., 2012). Asymptomatic throwing athletes have been reported to have several adaptations in their dominant shoulders during humeral elevation tasks. However, there is no clear evidence of a causal relationship between altered scapular kinematics and shoulder injury (Downar et al., 2005).

Upward scapular rotation is one of the constituent movement directions of the scapula and during humeral elevation tasks it can rotate approximately 60° relative to the thoracic cage (McClure et al., 2001). Upward rotation is important during overhead activity to prevent impingement of the rotator cuff (Downar et al., 2005); it prevents the humeral head from compressing against the acromion and thus creating a narrow subacromial space (Myers et al., 2005). Decreased upward rotation has been found to have a high correlation with shoulder injury (Oyama et al., 2008; Borsa et al., 2003; Burkhart et al., 2003; Kibler, 1998; Ludewig et al., 2000). Both Borsa et al. (2008) and Myers et al. (2005) reported increased upward rotation of the scapula in healthy overhead throwing athletes compared to non-throwing athletes. In addition, a significantly larger amount of scapular upward rotation compared to their non-dominant shoulder was observed in the dominant throwing arm of professional baseball pitchers (age 20 SD 1.6 years) with no previous history of shoulder injury (Downar et al., 2005 & Laudner et al., 2007). Furthermore, in populations of pitchers aged between 10 and 20 years of age, scapular upward rotation has

been found to decrease with age (Mourtacos et al., 2003; Thomas et al., 2010). However, these were cross sectional studies that did not address the possible decrease of upward rotation occurring in time in baseball pitchers.

The aim of the present study was to examine the asymmetry in and the development of scapular upward rotation over a one-year period within a group of elite youth baseball pitchers. To this end, it was examined quantitatively whether scapular upward rotation is different between the dominant (throwing) arm and the non-dominant arm, whether scapular upward rotation of the dominant arm changes over a one-year period, and whether these potential effects are different for players of different ages. Based on previous studies, it was hypothesized that pitchers will demonstrate a greater upward rotation in the dominant arm than in the non-dominant arm and that the asymmetry decreases with age.

Method

Participants and study design`

Data were collected from 92 male baseball pitchers (mean age=15.1 SD 1.4 years, mean body height=177.3 SD 10.9 cm, mean body weight=69.2 SD 14.5 kg), who were playing in the Dutch baseball academies and/or the national youth (AAA) baseball team. Participants were tested twice. The pre-test was conducted in April 2014 and the post-test in March 2015. A division in two age groups was made, based on the team division in the local baseball competition, a younger (n=56, age=13.8 SD 0.99 years) and an older (n=36, age=16.6 SD 0.92 years) group. The research design and protocol were approved by the local ethical committee of the Department of Human Movement Sciences before its conductance. Informed consent was obtained from the parents of the participants before participating in the study.

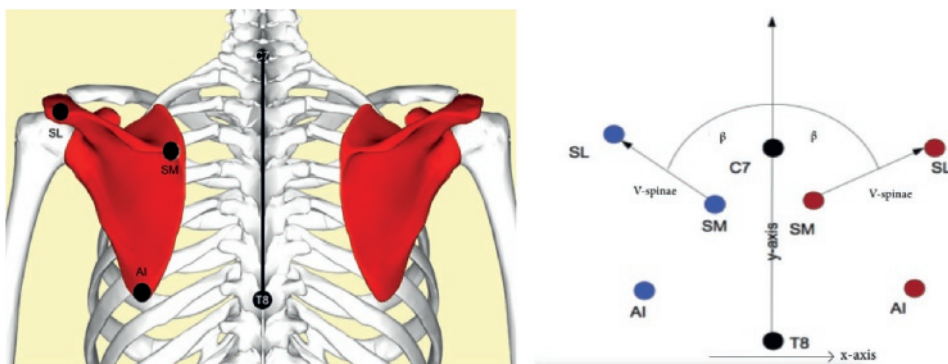


Figure 1a + b (a) Anatomical landmarks C7, T8, SL (Spina Scapulae Lateralis), SM (Spina Scapulae Medialis) and AI (Angulus Inferior), and (b) explanation of angle β , which was calculated using vectors SM-SL and T8-C7 (see equations 1-4).



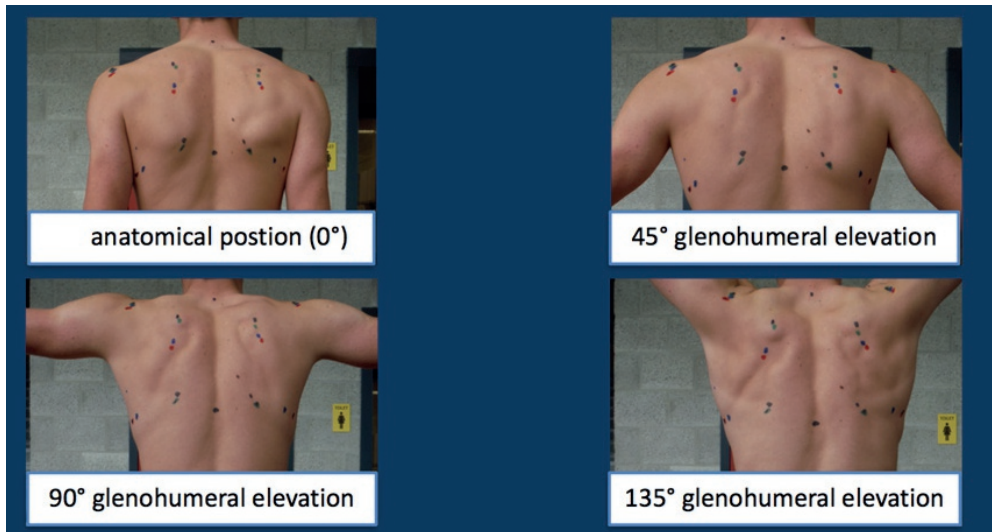


Figure 2 Example of the four positions in which anatomical landmarks were palpated and marked. Results of the palpation were marked with colored permanent markers: black 0°, green 45°, blue 90° and red 135°.

Procedure

For the purpose of the present study, the trigonum spinae (SM), angulus acromialis (SL) and the angulus inferior (AI) (figure 1) of the scapula were palpated and marked with coloured permanent markers on the skin at different glenohumeral (GH) angles of elevation in the scapular plane: anatomical position (0°), 45°, 90° and 135° (figure 2). No specific warm-up was performed before palpation. All tests were performed after school hours (as replacement of a regular training). A trained and experienced physiotherapist conducted all palpations. Corresponding to the bony landmarks, SM, SL and AI were located and their coordinates identified. The angle of the scapula with respect to the spine was determined with these coordinates using custom Matlab programming (The MathWorks, Inc, Natick, MA, USA). The spine, which served as the y-axis, was defined as the vector from the marker at cervical vertebrae 7 (C7) and thoracic vertebrae 8 (T8) and normed to length one (equation 1)

$$Y(\text{axis}) = \frac{[X(C7) \ Y(C7)] - [X(T8) \ Y(T8)]}{\|[X(C7) \ Y(C7)] - [X(T8) \ Y(T8)]\|} \quad (\text{eq. 1})$$

The x-axis was defined perpendicular to the y-axis (equation 2).

$$X_{(axis)} = [(Y(y) \ Y(-x))] \quad (\text{eq. 2})$$

The scapula was defined as a vector (V_{spinae}) from SM to SL (equation 3).

$$V_{spinae} = [(X(sl) \ Y(sl))] - [(X(sm) \ Y(sm))] \quad (\text{eq. 3})$$

The angle β was calculated as the angle between the vector of the y-axis and the vector V_{spinae} (equation 4).

$$\beta = \cos^{-1} \left(\frac{X(axis) * V_{spinae}}{\|X(axis)\| * \|V_{spinae}\|} \right) \quad (\text{eq. 4})$$

The upward rotation was calculated as $90^\circ - \beta$. In this way, when the scapula was horizontal, the angle for upward rotation was 0° .

Statistical analysis

To determine whether the amount of scapular upward rotation (β ; dependent variable) was different between the dominant and non-dominant arm and whether these differences were affected by the level of arm elevation (0° , 45° , 90° , 135°) and age group (young and old), data from the pre-test were analyzed statistically using a three-way mixed design ANOVA. A three-way mixed design ANOVA was also used to examine whether the scapular upward rotation of the dominant arm was different between the pre-test and post-test and whether these differences were affected by the level of arm elevation and age group. One-way within- and between-subjects ANOVAs with Bonferroni correction were used to examine if the interaction effects were significant. The assumption of normality was checked by means of visual inspection of the histogram, q-q plot and the box plot of the data within the groups. Z-values of skewness and kurtosis, and a Shapiro-Wilks test were also performed on the data. Homogeneity of variance was checked using Levene's test. There were no violations of these assumptions. All statistical analyses were performed in SPSS v23.0.0.2 (IBM Corporation, Armonk, NY, USA) and a p-value below 0.05 was considered significant.

Results

Asymmetry in scapular upward rotation

Asymmetry between the dominant and non-dominant arm was 5.10° on



average (95% CI: 2.07° - 8.13°, $F(1,56) = 11.36$, $p < 0.001$), with the dominant arm showing more upward rotation than the non-dominant arm. There was no significant interaction effect of age group ($F(1,57) = 1.13$, $p = 0.293$) or angle of arm elevation ($F(3,171) = 1.43$, $p = 0.235$) on the asymmetry. Dominant and non-dominant scapular upward rotation for all studied angles of arm elevation is displayed in figure 3

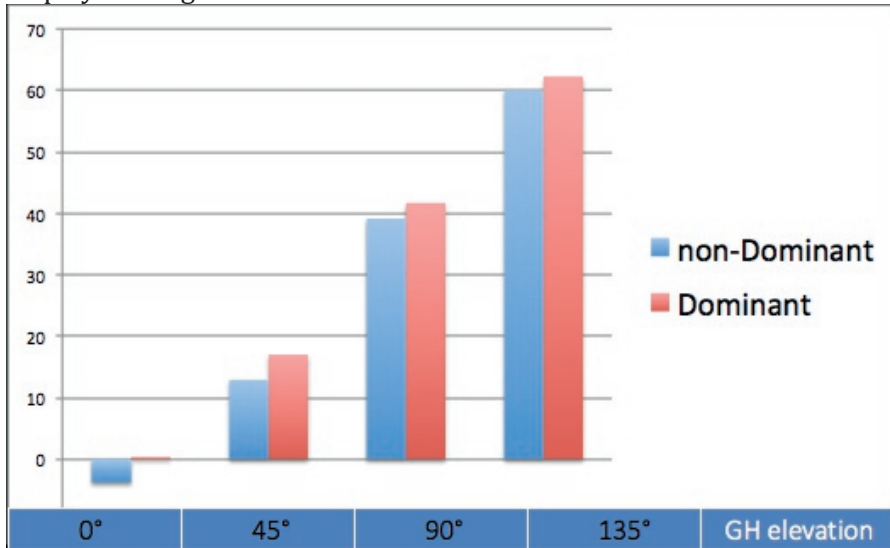


Figure 3 Upward scapular rotation for the dominant (throwing) arm and non-dominant arm for the different GH-elevation angles.

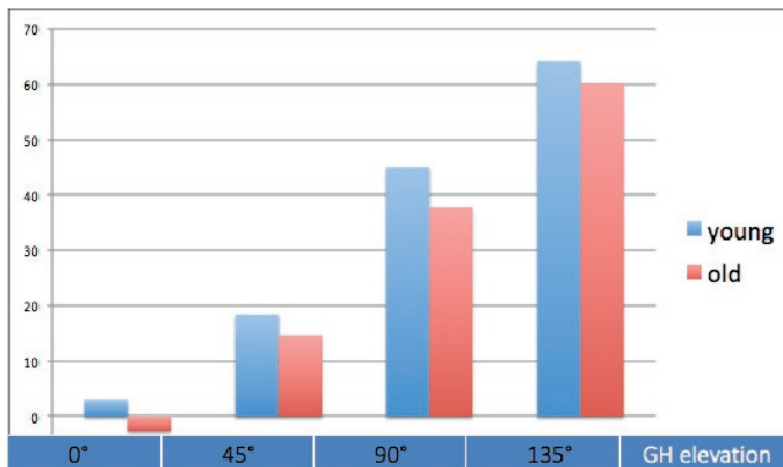


Figure 4 Upward rotation of dominant scapula for the young and old age groups and for the different GH-elevation angles.

Change in scapular upward rotation of the dominant arm

The scapular upward rotation of the dominant arm decreased with 1.88° on average over the one-year period, but this change was non-significant (95% CI: $-0.52^\circ - 4.28^\circ$, $F(1,37)=2.53$, $p=0.120$). The scapular upward rotation of the dominant arm is shown for both age groups and the four angles of GH-elevation in figure 4. Age group did not significantly affect the change in scapular upward rotation during the one-year period ($F(1,37)=1.53$, $p=0.224$). Also, the interaction between time (pre-test / post-test) and angle of arm elevation for scapular upward rotation was not significant ($F(1.95,72.18) = 1.58$, $p=0.213$) (figure 5).

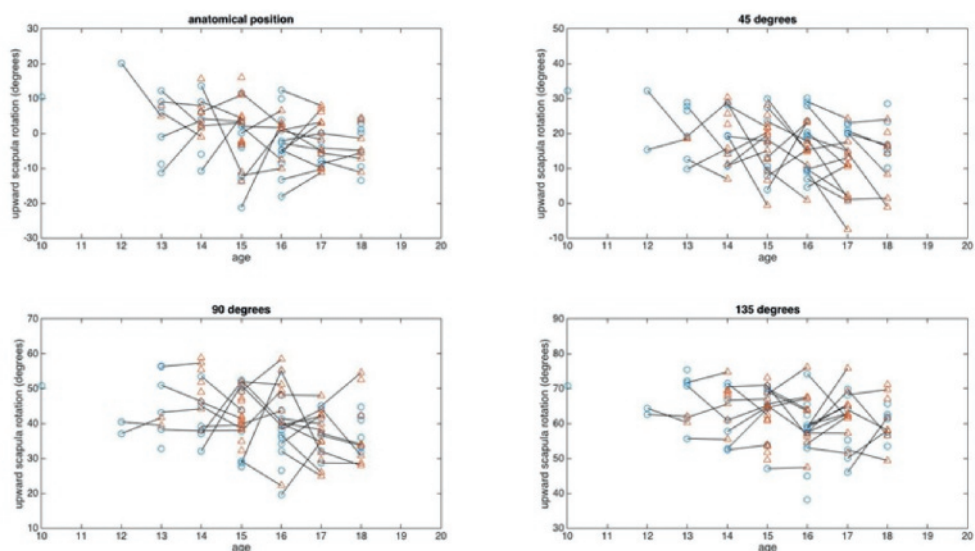


Figure 5 Development of upward rotation between pre-(O) and post(Δ) testing. Lines connect results per player.

Discussion

As hypothesised, we found an asymmetry in scapular upward rotation between the dominant and non-dominant shoulder in elite youth baseball pitchers. However, no significant differences were found between the group of 12-15 years of age and the group of 16-19 years or for different angles of GH-elevation. Also no significant evolution of the scapular upward rotation was found over the one-year study period.

Asymmetry in scapular upward rotation

The magnitude of asymmetry in upward rotation found in the present study



(5.10° on average) is similar to that in a couple of other studies (2.1° (Thomas et al., 2010), 3.1° (Mourtacos et al., 2003), and 3.6° (Downar et al. (2005), the latter for 90° degrees arm elevation only). In the present study, asymmetry in upward rotation was observed for all angles of GH-elevation in the absence of a significant interaction effect between arm elevation angle and upward rotation. The present study aimed to cast light on the evolution of this asymmetry as well. However, no significant difference in asymmetry between age groups was found, although such a cross-sectional difference has been reported in other studies (Thomas et al., 2010; Tsai et al., 2003). A factor contributing to the difference between age groups could be a proportionate increase in muscle strength of the older age group due to the higher amount of testosterone in older age groups (17-18 years old) compared to younger age groups (11-12 and 13-14 years old) (Ramos et al., 1998). For the elite youth pitchers of the present study, it could be considered that the main factor contributing to the asymmetry is that pitchers only throw with their dominant arm. This was the case for both age groups (12-15 years and 16-19 years) and differences in muscle growth between these age groups apparently not cause differences in asymmetry in upward rotation. However, the method used to assess scapular upward rotation yielded quasi-static measurements, which represents a limitation; the exact position of the scapula can be different in upward or downward movement of the arm, especially when a pitcher has less scapular control. Also our marker method is less accurate as for instance x-ray measurements, but we expect our method to be valid, particularly because a trained and experienced physiotherapist conducted the palpation.

Change in scapular upward rotation of the dominant arm

The present study showed a non-significant decrease in the scapular upward rotation in youth baseball pitchers of 1.88° over the one-year study period (95% CI: -0.52° – 4.28°). A decrease in scapular upward rotation in the 16-19 years old age group was expected because an increase of the posterior capsule thickness of the dominant arm has a positive relationship with upward scapular rotation, leading to fatigue-related inhibition of the scapular muscles on the long term (Thomas et al., 2010). However, the mean decrease in scapular upward rotation observed over the one-year study period was not significant and there was no significant interaction effect for age group, suggesting that both age groups demonstrated comparable changes in scapular upward rotation. Nevertheless, the results of the present study might be clinically important. Apparently, the older participants in this study of youth baseball pitcher exhibited not more scapular upward rotation compared to the younger participants and also no significant increase was observed within both age groups over a year. It can generally be assumed, however, that the physical strength increases of these young pitchers increases as they grow older, and therefore throw faster. As

several studies indicated that a decrease in scapular upward rotation may be associated with an increase in (shoulder) injury risk (Oyama et al., 2008; Borsa et al., 2003; Burkhart et al., 2003; Kibler, 1998; Ludewig et al., 2000), monitoring these – and other – young elite pitchers in their physical development, for instance for scapular upward rotation, and their performance (throwing speed) might be important in the prevention of pitching-related shoulder symptoms. Thus, future research should focus on assessing scapular motion over a longer time period during the development of young athletes, especially in asymmetric, injury prone sports, such as baseball pitching.

Conclusion

This study showed that the dominant arms of elite youth baseball pitchers exhibit more scapular upward rotation compared to their non-dominant arm. However, scapular upward rotation was not greater for the older pitchers as compared to the younger pitcher and it also did not increase over the one-year study period in either age group. As a result of the asymmetry in upward scapular rotation, these athletes could be at risk to develop shoulder injuries, and thus in the training program of these athletes specific exercises could be incorporated to minimize scapular upward rotation of the throwing arm.



incidence of INJURIES

WRIST
8 injuries
46 injured days

SHOULDER
98 injuries
1820 injured days

ELBOW
84 injuries
2109 injured days

BACK
140 injuries

HIP
12 injuries

KNEE
45 injuries

ANKLE
22 injuries

every 6 months

3 years

125 pitchers

10.5 years
43 mph
1.47 m
35 kg



441 total tests

total number based on self-reported injuries 'in the past 6 months'



19.6 years
88 mph
2.03 m
112 kg



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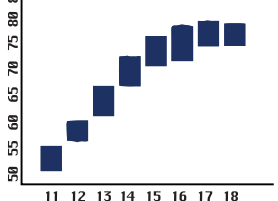
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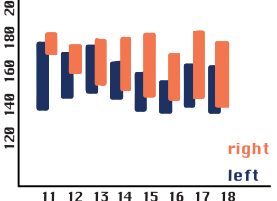
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DEVELOPMENT of youth pitchers

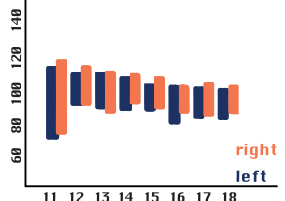
(mph) throwing velocity



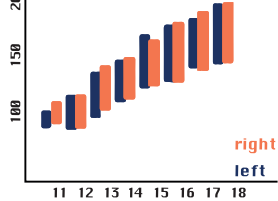
(°) shoulder ROM



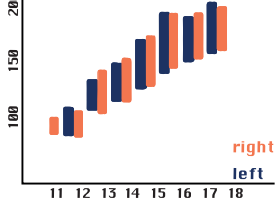
(°) hip ROM



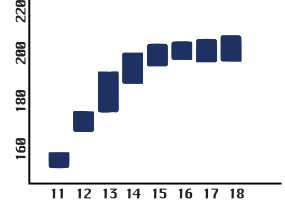
(Nm) endorotation strength



(Nm) exorotation strength



(cm) span width



boxplots represent 25-75% interval per age category (11-18 years)

THROWING FAST is related to..



strength of shoulder rotation



timing of rotations between segments

relative long arms



Part II



Chapter 5

Focus of attention instructions during baseball pitching training

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Abstract

It has often been shown that performance and learning in movement tasks may be improved by focusing on the effect of the movement in the environment (external focus of attention) instead of the movement itself (internal focus of attention). Nevertheless, most coaching instructions and feedback information given in sports seem to favor an internal focus of attention over an external one. In the present study we investigated coaches' instructions and feedback in an instrumental sports action, viz. baseball pitching, in which external targets are readily identifiable, such as the strike area or the catcher's glove. To this end, we recorded and analyzed the pitching instructions and feedback statements of six baseball coaches given to 70 elite youth baseball pitchers (mean age 15.3 (*SD* 1.67) years) during regular pitching training sessions over a training period of four weeks. All instructions and feedback statements were classified according to the type of focus of attention invoked (i.e. internal or external), and a rest category of all other statements. Of the statements promoting a specific focus of attention (717/1699), only 31% (224/717) were classified as external focus of attention statements. Correspondingly, the responses on a questionnaire filled out by the pitchers indicated that they used an internal focus of attention during practice and preferred to receive internally oriented over externally oriented instructions and feedback. The present results show that, also in sports involving clear external targets such as baseball pitching, internal focus of attention instructions prevail, the experimental evidence in favor of external focus of attention instructions notwithstanding.

Keywords Instructions, Focus of attention, Coaching, Baseball, Training



Introduction

Baseball pitching is a complex action in which the entire body is involved in generating a very high throwing velocity. The fastest pitch ever recorded was clocked at 105.1 mph (169.1 km/h). Thus far, research on baseball pitching served two aims, namely to understand how to generate high throwing velocities and how to minimize musculoskeletal injuries by optimizing the throwing technique. In general, great strength and explosive power are needed to generate high throwing velocities (Stodden et al., 2005). In addition, a delicate task-specific coordination of body parts is required for optimal pitching performance (Putnam, 1993; van den Tillaar et al., 2009). Previous research has focused on prominent features of the pitching action, such as the extension of the front leg and the time separation between pelvis and trunk rotation (van der Graaff et al., 2016). However, many aspects of the task-specific coordination required for optimal pitching performance are still not fully understood. Apart from gaining a better understanding of the pitching action, elucidating these aspects may help to identify and support young talented pitchers through training. An important question in this context is what types of instruction and feedback should be given to young talented pitchers in order to improve their pitching technique and thus their throwing velocity.

Previous research has suggested that instruction and feedback determine the focus of attention adopted by actors, which in turn affects both performance and learning (Wulf et al., 2001c). In particular, a distinction has been made between instructions with an external focus of attention, in which attention is focused on the effects of the movement in the environment, and an internal focus of attention, in which attention is focused on the movement itself (Wulf et al., 1998a). Importantly, several studies on a variety of tasks, including far-aiming tasks, jumping tasks (Porter et al., 2010b; Wulf et al., 2010b; Zachry et al., 2005) and agility tasks (Porter et al., 2010a), have shown that an external focus of attention may improve performance and learning more than an internal focus of attention (Beilock et al., 2002; Wulf, 2007; Wulf et al., 2001c). Although the advantages of external focus of attention instructions for both performance and learning have been amply demonstrated (Porter et al., 2010a; Wulf, 2007; Wulf et al., 2007; Wulf et al., 2001c), most coaching instructions in sports still tend to promote an internal rather than an external focus of attention. Evidence for this was found in a study in which 13 track-and-field athletes from 10 disciplines (8 running disciplines, javelin and triple jump) were interviewed about the instructions they received from their coaches (Porter et al., 2010c). The coaches in this study predominantly provided instructions and feedback about movement characteristics (85%), which, in all likelihood, led the athletes to adopt an internal focus of attention. However, in view of the results of studies comparing the effects of external and internal focus of attention instructions on performance and learning, this might not have led to the best possible

performance and learning outcomes.

Although the main finding of the Porter et al. (2010) study is interesting in that it raises questions about the relationship between sports science and sports practice, it suffers from three limitations that preclude generalization of this finding to other sports. First of all, as recognized by the authors themselves, the sample size of 13 athletes is (much) too small to warrant generalization. A second limitation, also acknowledged by the authors, is that the reliability of their finding depends on the recall capabilities of the interviewed athletes rather than direct recordings of the instructions given by the coaches in authentic practice situations. A third limitation, not noted by the authors, is that the 10 track-and-field disciplines cannot be seen (at least not a priori) as fully representative for, or equivalent with, other sports disciplines with regard to the topic under investigation (i.e. internal versus external focus of attention instructions). It may be, for instance, that internal focus of attention instructions prevailed in the track-and-field disciplines of interest simply because external focus of attention instructions are less readily identifiable in these disciplines than in other sports. For example, running is a cyclic activity with little external reference points, giving the coaches less opportunity to provide instructions and feedback pertaining to the external effect of the movement in the environment. In contrast, instrumental sports actions, such as hitting a tennis ball or shooting a basketball, involve a clear environmental goal and thus provide a direct opportunity for giving external focus of attention instructions. Also baseball pitching is a discrete aiming task with a clear environmental goal, namely to throw the ball through the strike area of the batsman into the glove of the catcher, which can be readily translated into external focus of attention instructions, for instance by having the pitcher focus on the batsman's strike area or the catcher's glove. In light of this difference between tasks, it could be that coaches are more inclined to use instructions and feedback in baseball pitching training that invoke an external focus of attention than track-and-field coaches and that such instructions and feedback are experienced as more common by the pitchers themselves. The main aim of the present study was to examine to what extent baseball coaches invoke an external focus of attention when instructing elite youth players in baseball pitching training, i.e. a discrete aiming task with a clear environmental goal. In doing so, we sought to avoid the two other limitations of the study by Porter et al. (2012) as much as possible.

To this end, we recorded all the instructions and feedback given by coaches during actual training sessions for youth baseball pitchers (i.e. in authentic practice situations) and then classified these instructions according to the type of focus of attention invoked by them (i.e. internal or external), or none at all. Given previous research, we expected a prominent role for instructions and feedback with an internal focus of attention but relatively speaking a greater percentage of instructions and feedback with an external focus of attention than



have been observed in track and field, given the aforementioned task difference. In addition, we were interested in exploring the (potential) associations between the instructions given by the coaches and the goal of the training sessions, i.e. to improve pitching performance, as well as the players' disposition towards those instructions. As regards the former objective, we measured how the throwing velocity evolved over the training sessions. The instructions given by the coaches were intended to improve pitching performance, and it is hypothesized that differences in the type of instruction provided by the coaches led to statistically different changes of the improvement of performance. As regards the latter objective, we measured the propensity of players to reinvest via the MSRS, as well as how they focused their attention during training (as measured with the BSQ) and the type of instruction they preferred (as measured by open-ended questions).

Method

Participants

Seventy male pitchers and six male coaches, each connected to one of the six baseball academies in The Netherlands, were recruited for the present study. The baseball academies in question deliver teams that compete in the Dutch youth elite leagues. All pitchers ($n = 70$, mean age 15.3 years ($SD 1.7$)) were experienced and skilled players within their age category (playing experience = 9.6 years ($SD 2.8$)), with dedicated pitching experience (mean 6.9 years ($SD 2.8$)). Before each training session an attendance and injury check was performed in order to exclude any participants who were not sufficiently fit to participate in the present study. Coaches ($n = 6$, age 42.5 years ($SD 13.1$)) had a minimum of 6 up to 30 years of baseball experience, as player (in the Dutch major league up to the MLB minor leagues) and as coach. Both players and coaches were informed about the project in very general terms without explaining the specific goal of the study or mentioning the variables of interest besides throwing velocity. Given that the present study was an observational study, neither pitchers nor coaches received any form of instruction or feedback from the researchers during the study. All participants and their legal representatives signed an informed consent form before the study was initiated.

Procedures

The study was conducted in February 2015 during the final four weeks of winter training, before the start of outdoors practice. The intention was to visit all six coaches once per week for four weeks. All practice sessions were indoors. Due to holidays 'coach 1' cancelled two training sessions and 'coach 3' cancelled one training session, while 'coach 4' was absent for one week due to illness.

In order to record all instructions from the pitching coaches, each coach was equipped with a voice recorder (Olympus Memo recorder VN-7600) during

each training session. The voice recorder was active during the entire training session. In addition, each training session was filmed with a camera (Casio XLZR 1000) in order to record which specific practices were performed.

Depending on their age and team, the players threw a minimum of 10 and a maximum of 45 balls from the pitching mound during each training session. The throwing velocity of all throws from the pitching mound was measured using a Stalker Pro II Sport radar gun (Applied Concepts Inc., Plano, TX) and the mean throwing velocity for each player and each (weekly) session was calculated.

After the first and last practice, the players filled out the Dutch version of the Movement Specific Reinvestment Scale (MSRS) (Kal et al., 2016a), which measures a person's propensity to consciously monitor and control movements (i.e. to 'reinvest' conscious control in automatized movement execution). The MSRS questionnaire consists of 10 items, 5 of which relate to movement self-consciousness and 5 of which relate to conscious motor control. The latter 5 items indicate if one tends to adopt an internal or an external focus of attention during physical activities. The MSRS was originally developed by Masters et al. (Masters et al., 2005) in the English language and translated into Dutch by Kleynen et al. (Kleynen et al., 2013). Kleynen et al. and subsequently Kal et al. (Kal et al., 2016a) found the Dutch version of the MRMS to be a reliable tool to assess the propensity for movement-specific reinvestment, with intra-class coefficients of 0.81 and 0.91, respectively. Furthermore, after each practice session, the players had to fill out a Baseball Specific Questionnaire (BSQ) with no established validity and reliability. This questionnaire was developed in order to obtain more information about the focus of attention used by the players during practice. The BSQ questionnaire was derived from studies by Maurer and Munzert (Maurer et al., 2013) and Porter et al. (Porter et al., 2010c), who used similar questionnaires to investigate the focus of attention used. The BSQ was designed as a "fake" motivational questionnaire with 10 focus related questions hidden throughout the 32 questions posed. The focus related questions were hidden such that the participants remained blind to the main goal of the questionnaire. These focus related questions consisted of 5 external and 5 internal related statements. Each BSQ had to be filled out in relation to the practice session that the participants just completed, so as to obtain information about their focus (or motivation) during the training session in question. Players had to indicate how much they agreed or disagreed with each statement by putting a cross on a 9 cm long line (resulting in a score of 1-10 with a score of 1 corresponding to 0 cm a score of 10 corresponding to 9 cm).

After the last practice session only, and after having filled out the two previously mentioned questionnaires, pitchers also had to answer two open-ended questions. In particular, they were asked to write down the three



instructions they perceived as most useful and the three instructions they perceived as least useful to accomplish a higher throwing velocity.

Data analysis

All voice-recorded comments of the coaches were written out, statement by statement, in an Excel file. All statements were divided into three categories. Comments were coded as invoking an internal focus of attention when they contained information regarding the correct placement of various body parts, the timing of sub-movements, or the overall dynamics of movement execution (Wulf et al., 1998a). Examples of such comments in baseball, taken from the recordings of the coaches, are: “Keep your shoulder in” and “Lift your leg up”. Comments that were directed at the effects of the movement in the environment were coded as invoking an external focus of attention; examples of such comments are “Aim at the mitt” and “Step on the line”). More examples are provided in Table 1 (Halperin et al., 2016). The third category consisted of all other statements made by the coach during the training, be it as stand-alone remarks or as part of a conversation or discussion. Two raters classified all statements into the three categories individually. On the basis of their scores, Cohen’s kappa for two-rater inter-rater reliability was calculated using the “irr” package in R (v 3.3.2, R Foundation for Statistical Computing, Vienna, Austria). The MSRS score was calculated by adding up the scores of the five focus-related statements of the questionnaire. Each statement was rated on a scale of 1 to 6 ranging from “strongly disagree”(1) to “strongly agree”(6). A low score, i.e. in the range 5-17, indicated a greater preference for an external focus of attention, while a higher score, i.e. in the range 18-30, indicated a greater preference for an internal focus of attention. The difference in MSRS score between the first and fourth week was analyzed using a paired samples *t*-test.

The 10 questions of the BSQ were given a score between 1 and 10, with a score of 1 indicating a preference for instructions that promoted an internal focus of attention and a score of 10 indicating a preference for instructions that promoted an external focus of attention. The overall score could thus be calculated on a scale from 10 to 100. Whether the BSQ score was dependent on coach and week was analyzed by means of a one-way ANOVA with repeated measures. The same analysis was performed for throwing velocity. Both the paired *t*-test and the ANOVA were performed in SPSS v 23.0.0.3, (IBM Corporation, Armonk, NY, USA) with significance set at $p < .05$. The between-subjects factor coach was added to determine if the coaches players differed in BSQ score and throwing velocity, thus indicating a possible association between instruction style, which potentially differs between coaches, and BSQ score or throwing velocity. The within-subjects factor week was added to examine if there were systematic week-to-week variations.

Table 1 Examples of recorded examples assigned to category 1 (internal focus) and to category 2 (external focus).

Comments evoking an internal focus of attention. (Category 1)	Comments evoking an external focus of attention.(Category 2)
Use your hip	Throw a strike
Keep your hand/shoulder in	Aim at the mitt
Lift your leg and then speed up.	Stay over your shoes
Finish your leg kick before you go home	Go straight to the plate
Get the left foot down	Keep the ball low

Table 2 The 5 questions of the MSRS related to conscious motor control and the 10 BSQ focus related questions.

MSRS
I reflect about my movement a lot I try to figure out why my action failed. I try to think about my movements when I carry them out. I am aware of the way my body works when I carry out a movement. I remember times when my movements have failed me
BSQ
I try to speed up the ball as much as possible. I try to move my arm as explosive as possible. I try to thow the ball away as fluently as possible. I try to move my arm as fleutnrly as possible. I think about the trajectory of the ball. I think about my movement during pitching. I try to spin the ball as much as possible when i throw a breaking ball. I try to snap my wrist as much as possible when i throw a breaking ball. I try to step down the mound as fas as possible I try to put my foot down good when I am pitching



Results

Coaches' instructions

Over 37 hours of recorded training sessions with 1699 individual statements were written out and subsequently categorized independently by two raters. Of all statements, 42% (717/1699) invoked either an internal or an external focus of attention. Only 31% (224/717) of these statements invoked an external focus of attention (Figure 1). Although there were differences in the type and number of statements given between coaches, all coaches used more statements that invoked an internal focus of attention rather than an external focus of attention (Figure 2). The inter-rater reliability (Cohen's kappa) was 0.76 (87.6% agreement), indicating substantial (defined as 0.61-0.80) agreement between raters (Cohen, 1960).

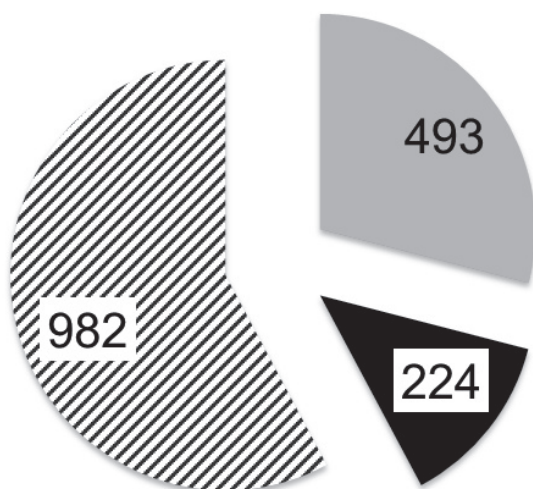


Figure 1 All statements categorized. Category 1 (gray): internal focus. Category 2 (black): external focus. Category 3 (lined): other comments.

MSRS

The score on the MSRS after week 1 was significantly higher than the MSRS score after the training period, $t = 2.247$, $p = .029$ (mean 22.65 (SD 4.07) vs mean 21.31 (SD 4.41)), indicating that participants were somewhat less internally focussed in their attention after the training period. Only two of the participants scored both times lower than 17 on the MSRS, indicating a propensity for an external focus of attention. Hence, the MSRS questionnaire scores showed that participants generally tended toward an internal focus of attention.

BSQ

The overall mean of the BSQ in week 1 was 56.0 ($SD = 6.7$). Neither a significant effect of week ($F(3,112) = .437, p = .727$) nor of coach ($F(5,112) = 1.006, p = .418$) was found. Hence, the mean BSQ scores for the six coaches and for the four weeks of the training period can be considered equal.

Open-ended questions

In response to the open-ended questions regarding the best and worst instructions, 44 players provided 117 instructions in total. Only four of the instructions that were deemed helpful by the players in increasing their throwing velocity were instructions invoking an external focus of attention. Sixteen players reported a statement that they did not find useful, 13 of which were instructions invoking an internal focus of attention. The explicit knowledge of the players mainly consisted of instructions invoking an internal focus of attention.

Throwing velocity

The overall mean of the throwing velocity in week 1 was 67.0 mph ($SD 6.6$ mph). There was a significant effect of coach ($F(5,143) = 1.006, p = .006$) but not of week ($F(3,143) = .119, p = .994$). Bonferroni post-hoc testing of the significant effect of coach showed that the players of 'coach 5' had a higher throwing velocity than players of 'coach 3' with a difference of 5.0 mph ($SE 1.5$ mph, $p = .016$) and 'coach 6' with a difference of 6.80 mph ($SE 2.3$ mph, $p = .048$).

Discussion

The aim of the present observational study was to examine to what extent the main finding of the study by Porter et al. (2010) applies to an instrumental sports action, i.e. baseball pitching, that, by its nature, gives more opportunities for giving external focus of attention instructions instead of internal focus of attention instructions than non or less instrumental sports actions like running. In doing so, we attempted to enhance reliability and validity of the study's findings by including a substantial number of participants (6 coaches and 70 pitchers) and by recording the instructions that were given in the actual training situation itself.

In the present study, over seventeen hundred coaching instructions and feedback statements were recorded during 37 hours of indoor elite youth pitcher training, and subsequently categorized according to the type of focus of attention they invoked. More than two-thirds (69%) of these statements invoked an internal as opposed to an external focus of attention, implying that most instructions were directed at the movement of the pitchers themselves. The observed predilection in baseball pitching training to provide instructions and feedback on the pitching movement themselves rather than on their effects



is congruent with the finding in the study of Porter et al. (Porter et al., 2010c) that 85% of the instructions given by track-and-field coaches invoked an internal focus of attention. This correspondence in results is interesting because the study by Porter et al. was focused predominantly on running, whereas the present study was focused on baseball pitching. Since baseball pitching, unlike running, provides ample opportunities to give pitchers instructions and feedback resulting in an external focus of attention, we hypothesized that external focus of attention instructions would figure more prominently in baseball pitching than in the track-and-field by Porter et al. This was indeed the case (31% vs 15%), although in both sports such instructions still formed the minority of all focus of attention instructions given. Importantly, this was also found to be the case in a recent study by Halperin et al. (2016) on the ringside feedback provided during boxing matches.

To obtain more insight into the focus of attention of the players during practice besides the instructions given by the coaches, the pitchers filled out multiple questionnaires. The verified MSRS questionnaire indicated that players used an internal focus of attention during practice. However, our self-developed BSQ did not indicate any preference; perhaps this was due to the fact that players tended to respond positively to all instructions of the BSQ, regardless of type (i.e. internal or external focus). In this context it should be noted that as of yet no psychometric characteristics of this questionnaire are available. The answers to the open-ended questions indicated, however, that the majority of the instructions reported by the players themselves were instructions and feedback statements about movement characteristics, reflecting an internal focus of attention.

In sum, internal focus of attention instructions prevailed in both the recorded coaching instructions and the instructions reported by the pitchers themselves. Apart from the nuance that external focus of attention instructions figured somewhat more prominently in baseball pitching training, this result is consistent with the main result of Porter et al. (2010) for an instrumental sports action, and thus contributes to its generalizability. The apparent generality of this finding is remarkable in light of the strong evidence for the superiority of an external focus of attention over an internal focus of attention in motor performance and learning in different laboratory tasks (Wulf, 2007; Wulf & Prinz, 2001) and sport domains (Freudenheim, 2010; Zarghami et al., 2012) that requires further consideration and analysis. In our view, the most plausible explanation for our main finding and that of Porter et al. is that a gap still exists between sports practice and sports science in that results obtained in scientific research are not (yet) implemented in practice. Because coaches still give instructions invoking an internal focus of attention, players prefer such instructions since they are used to them and assume that they are effective (Maurer et al., 2013). This being said, there remains a need for field experiments

in which the effects of instructions invoking either an internal or an external focus of attention are examined in real sport contexts and ideally over longer episodes than have typically been studied in previous research.

Conclusion

In baseball, pitcher training coaches mainly employ internal focus of attention instructions, i.e. instructions that direct attention at the movement itself. Likewise, pitchers mainly report to use internal focus of attention instructions in improving their performance. The present results indicate that, also in sports involving clear instrumental actions, i.e. motor tasks with clear environmental effects, such as baseball pitching, instructions and feedback invoking an internal focus of attention instructions prevail, the experimental evidence in favor of external focus of attention instructions notwithstanding.





Chapter 6

External vs internal focus of attention in day-to-day baseball pitching training - a multicenter, randomized controlled cross-over intervention involving four national youth teams

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Abstract

Many studies have shown for a variety of tasks that both motor performance and learning benefit from instructions invoking an external rather than an internal focus of attention. However, whether this finding also applies to the regular training practice of elite athletes and over long training periods is unknown. To fill this lacuna, the effects of both instruction types on pitching performance (in terms of velocity, accuracy and technique) were compared in a multicenter, randomized controlled cross-over study involving four European national youth baseball teams. No significant differences as a result of instruction type were found with regard to the development of throwing velocity and accuracy over time, whereas internal focus of attention instructions led to a significantly better progression in pitching technique than the external focus of attention instructions after the cross-over. These findings call for a reappraisal of the alleged importance of an external focus of attention in elite sports training.

Keywords: Instructions, Focus of attention, Coaching, Baseball, Training



Introduction

Pitching a 90 mph fastball in baseball is a complex action that requires years of training to master. This explosive action is accompanied with high musculoskeletal stress, which makes pitchers prone to injuries. Elbow and shoulder injuries in particular are common among pitchers and known to undermine the pitching performance (Fleisig et al., 1995; Seroyer et al., 2010). In the development of baseball pitchers two opposing aims play a key role, namely to achieve an optimal pitching technique resulting in high-velocity throwing and to avoid injuries, especially of the upper extremities. These two aims stand in conflict since overuse is a main factor in injury development, whereas excellence can only be achieved through extensive training (Ericsson, 2014). To minimize injuries due to overuse, the number of pitches thrown are counted and restricted during both training sessions and matches.

In accordance with the aforementioned aims, scientific research has focused predominantly on assessing optimal pitching mechanics to enhance performance and to identify injury mechanisms. High speed, three-dimensional kinematic assessments have often been used for this purpose, but also have become an integral part of the development and training of elite pitchers, which in turn has led to an increased interest in the optimal pitching technique. As a result of this development, the optimal timing of pelvis and trunk rotational movements for achieving a maximal throwing velocity has recently become a topic of debate with respect to pitching technique (Sgroi et al., 2015; Urbin et al., 2013; van der Graaff et al., 2016). Kinematic analyses and quantification of the timing of pelvis and trunk rotational movements provide the trainer and pitcher with information that can be used not only to optimize the elite pitcher's throwing technique, but also to teach youth baseball players how to pitch properly and effectively.

A both theoretically and practically relevant question is how a proper pitching technique is best acquired through training and taught via instruction and feedback. This is an intricate issue because the domain of motor learning is rife with theoretical concepts and corresponding training methods, all of which have received empirical support (e.g., operant conditioning, implicit learning and differential learning, to mention but a few). In the context of the present study we concentrate on the role of attention in developing the ability to pitch at high velocities. The reason for this choice is that a wealth of studies have shown that attending to the effect of movements in the environment (external focus of attention), rather than the movements themselves (internal focus of attention), is beneficial to both motor performance and the acquisition of motor skills (Wulf, 2007; Wulf et al., 2001c).

To set the context for the present study, a systematic review of the extant focus-of-attention literature (see appendix I for methodological details) was performed with the aim to provide an overview of the studies published

to date. Thirty-three studies using a sports(-like) task to compare the effects of internal versus external focus of attention instructions on motor performance and learning were found eligible and included in this systematic review. From these studies, the following information was gleaned and presented in Table 1: the experience of the participants, the task under investigation, the nature of the study (lab or field), the number of trials and the study's duration. As can be appreciated from this table, the vast majority of the *performance* studies – i.e. studies investigating the effect of one's focus of attention on a specific task or skill – were conducted with students (or university employees) who performed a limited number of trials in a sports(-like) context on a single day. The participants of the *acquisition* studies – i.e. studies investigating the effect of training with either an internal or external focus of attention on the acquisition of a specific task or skill – were (again) mainly college students who took part in series of practice trials under controlled conditions that covered a time span of three training days at most, except for the study of Woo, Yi, and Koh (2014) that lasted 8 weeks and the study of Chow (2014) that consisted of 6 training sessions. It is thus fair to conclude that the beneficial effects of an external focus of attention on motor performance and skill acquisition have mainly been demonstrated in relatively inexperienced subjects, in sports-like situations with limited ecological validity, and in studies of relatively short duration. There is thus a clear need to compare the effectiveness of an external focus of attention and internal focus of attention over a longer time span in well-trained individuals in an actual training environment involving regular instructors (Kakebeeke et al., 2013; Peh et al., 2011).

The aim of the present study was to provide such an examination by testing the hypothesis emerging from the literature that verbal instructions invoking an external focus of attention lead to superior acquisition outcomes compared to instructions invoking an internal focus of attention in regular baseball pitching training with trained pitchers over a longer period of time. To achieve this aim, a randomized controlled cross-over study was conducted involving a ten-week training program in which the best youth baseball pitchers of four European countries participated, using throwing velocity, throwing accuracy and throwing technique scores as the main outcome measures. The participation of (the pitchers of) four national youth teams allowed us to test (i.e., confirm or reject) the main research hypothesis in four different training contexts. The latter aspect not only contributes to the internal validity of the study, but also to its potential practical value, i.e. to its external and ecological validity. After all, if the main research hypothesis would be confirmed in all four training contexts, this would constitute independent evidence for its practical relevance.

Table 1. For Table 1, see Table X1, Introduction.



Method

Study design

A multicenter, randomized controlled cross-over study was performed involving the national youth (AAA) teams of Belgium, Germany, Italy and the Netherlands with a within nation allocation ratio of 1:1. An array of two numbers was randomly generated by a computer in order to allocate each athlete within the team to one of the two intervention groups (external-internal, E-I, and internal-external, I-E), yielding a similar number of participants in both groups. Group E-I (N=23) started with a five-week training program involving instructions invoking an external focus of attention, followed by a five-week training program involving instructions invoking an internal focus of attention. The five-week period was chosen to facilitate a minimum of at least 250 practice repetitions (pitches). The second group, Group I-E (N=22), received both training programs in the reversed order.

The study started with the first indoor bullpen session after the Christmas break in January 2016 and ended with the last indoor bullpen session before the first match of the season in March 2016 (MLB Elite tournament in Barcelona). This ten-week period is the longest period of uninterrupted training in the baseball calendar in Europe.

The cross-over design was chosen to explore the effects of the intervention with both a between and a within group comparison. Moreover, the cross-over design was helpful in convincing the teams and coaches to participate in our study as all subjects would receive the same intervention, such that each participant would have equal opportunity to take advantage of both types of instruction. However, a drawback of a cross-over design is that effects may carry over from the first to the second intervention period. Therefore, it was necessary to test whether such a carry-over effect occurred, that is, whether or not the start of the second training period could be considered neutral (Wellek et al., 2012).

Study population

Coaches of European teams and representatives of MLB were informed about the project at the MLB elite camp Regensburg 2015. The national U-18 (AAA) teams of Belgium, Germany, Italy, and the Netherlands agreed to participate in the project. All pitchers (N=45) had to be male and train at the level of their national U-18 (AAA) team. Pitchers who recently had been injured, or were involved in an adapted training program because they were recovering or suffering from an injury, were excluded from participation in the study. During the study, four players dropped out, three players became injured and one player was eliminated from the national team program.

The pitchers were informed about the goals of the study in general terms, but the theory behind the use of an external or an internal focus of attention in

training was not explained to them. The study protocol was approved by the local ethics committee of the Department of Human Movement Sciences. All participants and their legal representatives signed an informed consent form prior to participation.

Intervention development and design

Key points of the pitching motion were defined based on a combination of consultation with the coaches of the participating teams and results from empirical studies (Fleisig et al., 1999; Stodden et al., 2005; van der Graaff et al., 2016; Werner et al., 2008a). The key points in question were defined as a specific posture at a specific moment in the pitching motion allowing for reliable quantification. After a few meetings, coaches and researchers agreed unanimously on 10 key points that were deemed of decisive importance to throw faster and more accurate. The 10 key points were precisely defined to ensure that, based on high speed video (240 Hz), the stated key point could be easily rated as being accommodated (i.e. good posture) or not accommodated (i.e. bad posture). A document was created with concise explanations of the key points with accompanying pictures of all ten postures, together with examples of good and bad postures.

Next, specific exercises with accompanying instructions that addressed the specific key points or combinations of key points were created. These exercises were registered on video by the coaches and shared online. In addition, the coaches had to write down the instructions that should accompany that specific exercise. Together with the main researcher, the instructions were optimized to promote either a 100% external focus of attention during the exercises or an instruction to create 100% internal focus of attention. This participatory approach was chosen to let coaches have ownership over the exercises and instructions and to avoid that they had to use scientific language or felt they were top down instructed to organize a specific trainin\



Table 2. Examples of instructions evoking an internal and external focus of attention for 3 key points.

Instructions and feedback evoking an internal focus of attention.	Instructions and feedback evoking an external focus of attention.
<i>Key point 1: 'When squatting down, knee stays behind toe'</i>	
<p>Do not stand on your toes.</p> <p>Push your butt backward/Stick your ass out.</p>	<p>Do not touch the bat (put a baseball bat upside down in front of the back foot).</p> <p>Touch the pole with your butt (place a pole behind the pitcher on the mound).</p>
<i>Key point 2: 'During wind-up swing, arm stays in line with the shoulders'</i>	
<p>When moving your arm back, align your shoulders, elbow and hand.</p> <p>Do not extend you shoulder backwards.</p>	<p>Knock the ball from the T (place a T straight behind the player, during the wind-up he has to touch the ball of the T)</p>
<i>Key point 3: 'Knee of stance leg rotates inward before foot plant'</i>	
<p>Rotate your hip and knee inside before you put you foot down.</p> <p>When you push from the foot, rotate the knee inside.</p>	<p>Hit the cone with your knee before your front touches the ground (place a cone in between the legs, the knee of the push of leg has to touch the cone before foot plant).</p>
<i>Key point 4: 'When arm swings up, hand moves above shoulder line before elbow'</i>	
<p>During the wind-up, move your hand up.</p> <p>Rotate (supinate) your arm.</p>	<p>During the wind-up, move the ball towards the ceiling.</p>
<i>Key point 5: 'At MER, foot points at target'</i>	
<p>Rotate your foot (inside or outside).</p> <p>Keep your foot straight.</p> <p>Don't turn your ankle.</p>	<p>Step towards the target / step towards the cone (place a cone in front of the mound).</p> <p>Step on the line (tape a line on the mound).</p>

<i>Key point 6: 'The elbow is at the same height as, or higher than the shoulder'</i>	
Raise your arm/elbow.	Move the ball along the ceiling.
<i>Key point 7: 'Knee is extended through ball release'</i>	
When you put your foot down, pull it backwards. After foot plant extend your knee.	When you put your shoe down, pull the shoe backwards. Pull the band back (wrap an elastic band around the knee which is pulled forward, the player has to pull it backward, thereby extending the knee)
<i>Key point 8: 'Release point of the ball is in front of the front foot;</i>	
Extend your hand/arm as much as possible forward.	Reach with the ball towards the catcher.
<i>Key point 9: 'Thumb points down after ball release,'</i>	
Pronate your hand/arm after ball release.	After ball release, grab something from your pocket.
<i>Key point 10: 'Trailing leg rotates over the line between stance leg and catcher.'</i>	
Keep rotating your hips after the throw. Flex your upper body to the side after the throw.	Kick the ball to the side (put a ball in front of the pitcher, if the player kicks the ball he needs to rotate the leg through). After you throw step over the line (tape a line from pitcher to catcher).

The study consisted of two periods. The first period was from the baseline test (pre test) to the first post test (test 1), and the second period from the first post test (test 1) to the second post test (test 2) (Figure 1). Hence, test 1 served both as post test for the first period and as a baseline test for the second intervention period. Both intervention periods consisted of 8 bullpen sessions. During a bullpen session between 20 and 40 balls were thrown to a catcher. The training sessions were all indoors and all players started with a general warm-up. After the warm-up the group was split into the predefined intervention groups (Group E-I and Group I-E). One of the groups started with baseball specific field training or with strength and conditioning (non-pitching training), the other group first performed the pitching training and then performed the field training or strength and conditioning. The non-pitching training was only controlled within teams by instructing the coaches to give all pitchers within their team the same non-pitching training. The order in which the players received the



pitching and non-pitching training differed from training to training within teams. The intervention groups were not able to see the intervention or hear the instruction of the other group as they trained in different locations. All coaches were equipped with a recording device to be able to check whether the coaches instructed reliably, even if the main researcher was absent.

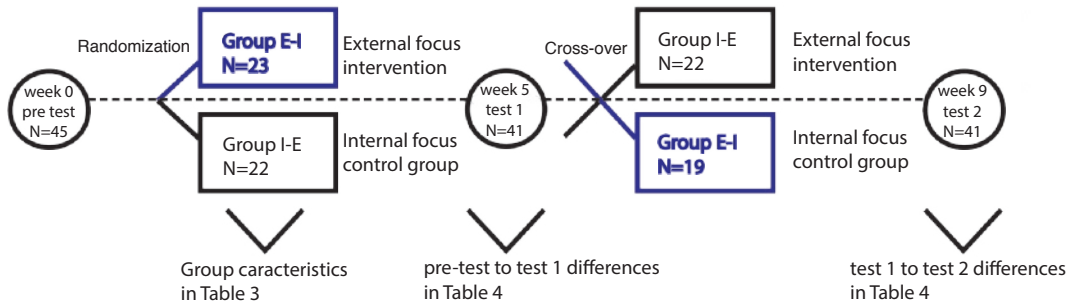


Figure 1 Study design

Five-week individualized training programs were created for each player, based on the results of the baseline measurements. Each individual schedule focused on the key points that could be improved for the player in question. During the actual intervention the coaches gave instructions and feedback on the key points a given player was working on, using only either an external focus of attention or an internal focus of attention based on the intervention group of the player. During each session the pitchers had to throw 20 to 40 times to six locations as depicted on a target sheet for reference (Figure 2). The order of these locations was randomized for the external focus intervention. For the internal focus intervention, the order was also randomized for the six locations, albeit that three pitches in a row were made to each location in order to reduce the number of times the pitcher had to focus at a new location, which could serve as an external focus cue.



Figure 2 Target sheet with six possible throwing locations as used during the bullpen sessions. The strike zone (inner 3 × 3 zone) was 45 cm wide and 55 cm high. In official games, the width of the strike zone is 17 inches (43.18 cm), with the batter’s body height determining the height of the strike zone.

Outcome measures

During the tests, the primary outcomes, i.e. throwing velocity, throwing accuracy and technical performance, were assessed during a bullpen session. The test consisted of 15 fastball pitches from a pitching mound to the catcher. Each pitch had to be aimed at one of the six locations as indicated on the target sheet. The order in which the target locations were presented was randomly generated by a computer and fixed for all tests and specified to the player by the coach or another pitcher who was standing at the normal referee position. No other instructions were given during the test.

The throwing velocity of all 15 pitches was recorded with a radar gun (Stalker Pro II Sport radar gun (Applied Concepts Inc., Plano, TX)) from behind the catcher.

The accuracy of each pitch was assessed by charting the observed location of the throw on the target sheet. For an exact hit at the targeted location a player received 2 points, for a 'near hit', a hit in a box next to the targeted location, 1 point was awarded. A player could score a maximum of 30 and a minimum of 0 points for accuracy. The accuracy score was calculated as the percentage of scored points of the total points.

The throwing technique was assessed by the principle investigator, who rated the throwing technique based on the 10 key points. To this end, high-speed video recordings were made of the pitching actions using three camera's (Casio XLZR 1000) running at 240 fps. One camera was placed straight behind the pitcher, one was placed at the throwing arm side of the pitcher, and the third camera was placed squarely before the pitcher. For every pitcher, three pitches (the 5th, 8th and 12th pitch of every test) were scored on the 10 key points. Each key point was rated in binary fashion as good, meaning exactly matching the description of the key point (1 point), or not good (not matching the description, 0 points). To check if the technique was matching the description, for each key point, the video frame was searched corresponding to that moment in the pitch (in the case of key point 5: 'MER') and at that moment the direction of the foot was checked (Figure 3). A maximum of 30 (best performance) and minimum of 0 points (worst performance) could be scored per test moment for each pitcher. To minimize the subjectivity of the scoring process, before the start of the intervention, a small sample size reliability study was performed. The percentage of overall agreement between four raters, over the 10 key points combined, was 84%. For the single key points with a lower percentage of agreement than the average, the description of the key point was rewritten to be more specific.





Figure 3 Example for scoring the technique based on the video snapshots for key point 5 'At MER, the foot point toward the target. First, MER is defined based on the side view (middle pane). Then, in the front view (left pane), it is clearly visible the foot does not point towards the target.

Statistical analysis

Body height, body mass, and baseline values of the outcome measures of the two groups were compared using independent t-tests to establish whether the groups were similar at baseline. Progress scores for every outcome variable separately were defined in the first period as the outcome variables of test1 minus pretest scores and in the second period as test2 scores minus test1 scores (figure 1).

To check whether carry-over effects were negligible, the T score and corresponding p-value were calculated using the method of Welleck and Blettner (2012). A significant ($p < 0.05$) T score would indicate that a carry-over effect from the first to second period should be considered.

To determine whether instructions invoking an external focus of attention lead to superior learning outcomes compared to instructions invoking an internal focus of attention in regular baseball pitching training with trained pitchers, independent t-tests and regression analyses using linear mixed models were performed. The t-tests were used to determine whether the progress scores from pre-test to test1 and from test-1 to test-2 of throwing velocity, throwing accuracy and throwing technique were different for group E-I compared to group I-E. Additionally, linear mixed models with random intercepts as well as

both random intercepts and slopes for ‘coach’ (i.e. team) were determined, to assess the effect of, and possibly account for, the level of team, and compared to models without random coefficients. The results of these regression analyses, and thus the effect of the level of coach on the outcomes, were accepted if the model fit was significantly improved by including random coefficients, as shown by a significant decrease in the -2 Log Likelihood value using a Chi-square test (Field et al., 2010). Differences in progress scores (and their 95% confidence intervals) between the E-I and I-E groups were thus evaluated using either an independent t-test, or a regression model with a random intercept for coach or a regression model with a random intercept and slope for coach. All statistical analyses were performed using R 3.3.1 (R Core team, Vienna, Austria) and p-values <0.05 were considered significant

Results

Descriptives

At baseline (pretest) player characteristics and outcome variables did not differ significantly between Group E-I and Group I-E (Table 3). The development of ball velocity and accuracy over the training sessions is shown in Figure 4. According to the method of Wellek and Blettner (2012), no significant carry-over effect was observed, indicating that a correction for a carry-over effect was not necessary.

Table 3 Mean (SD) of player characteristics and outcome variables of both intervention groups at baseline, and *p*-values for the difference between the intervention groups at baseline.

	Group E-I	Group I-E	Difference	<i>p</i> -value
<i>Body height (cm)</i>	185.4 (3.6)	183.9 (9.2)	1.5	0.60
<i>Body mass (kg)</i>	84.5 (5.9)	78.4 (10.8)	6.1	0.10
<i>Ball velocity (mph)</i>	76.2(4.4)	77.7(4.5)	-1.1	0.78
<i>Accuracy score (%)</i>	44.3(14.0)	43.3(14.0)	1.0	0.85
<i>Technique score</i>	15.0(4.0)	15.0(4.0)	0.1	0.85



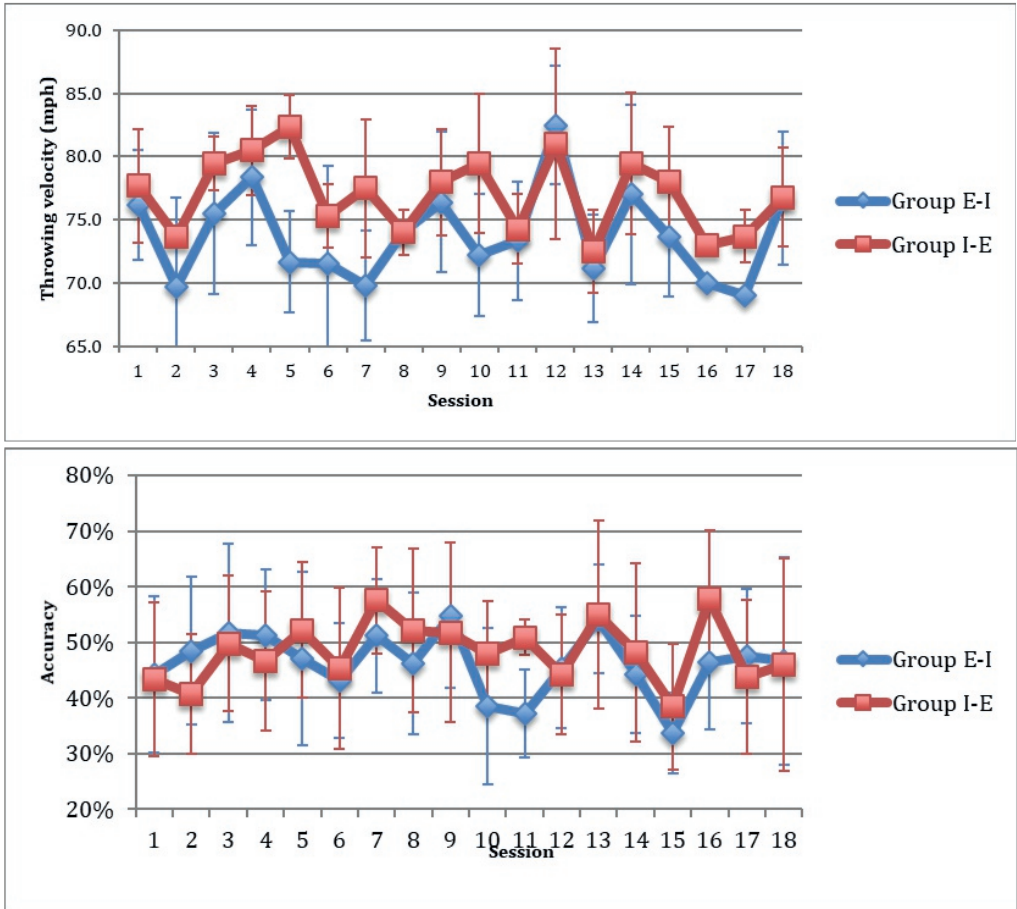


Figure 4 A+B Group means \pm 1SD of throwing velocity and accuracy for bullpen session during the entire study of nine weeks, session 1, 10 and 18 are the three tests.

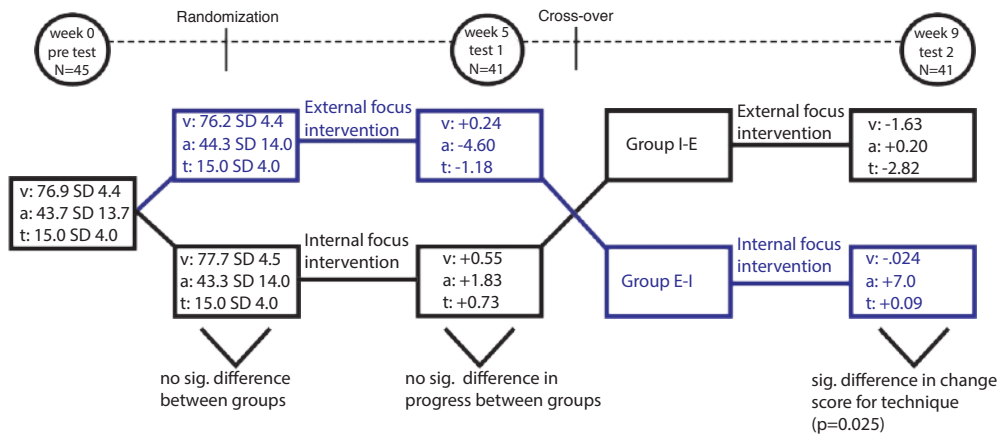


Figure 5 Main results (left to right) of the outcome of test1 before and after randomization. For test1 and test2 the change to the previous test are displayed per intervention group. v: throwing velocity in mph. a: throwing accuracy in % of scored points. t: technique score in points.

Table 4 Difference between intervention groups for changes in all outcome measures in both periods. *significant at p<0.05

outcome variable	difference in change between intervention groups	95% confidence interval	statistics used
Before cross-over			
Throwing velocity	-0.31	-1.77 - 1.15	t-test
Throwing accuracy	-6.4	-14.3 - 1.43	t-test
Technique score	-1.91	-4.97 - 1.16	t-test
After cross-over			
Throwing velocity	1.32	-0.40 - 3.04	Linear mixed model with random intercept for coach
Throwing accuracy	8.13	-1.6 - 17.97	Linear mixed model with random intercept for coach
Technique score	2.91*	0.38 - 5.44	t-test



Intervention outcomes

For the first intervention period – from pretest to test1 – no significant differences in the changes of all outcomes from pretest to test1 were observed between group E-I and group I-E (Figure 5, Table 4). For the second intervention period – from test1 to test2 - a significant difference between learning interventions was observed in the change of the technique score. The internal focus intervention in this second period had a more beneficial effect on the throwing technique than the external focus intervention (+2.91 points, 95% CI 0.38 – 5.44). This means that the internal focus group increased their technique score 10% more than the external focus group.

Discussion

The present findings provided no support for the research hypothesis emerging from the literature that instructions invoking an external focus of attention lead to a better progress of pitching performance – operationalized in terms of throwing velocity, accuracy and technique – compared to instructions invoking an internal focus of attention. No significant differences as a result of instruction type were found with regard to the development of throwing velocity and accuracy over time, whereas internal focus of attention instructions even led to a significantly better progression of pitching technique than the external focus of attention instructions after (but not before) the intervention cross-over. These findings call for a reappraisal of the alleged importance of adopting an external focus of attention in elite sports training.

There might be several reasons why the main research hypothesis, which has received robust support in short experimental studies involving mostly non-expert participants, was not corroborated in the present study. First of all, it might be that instructions invoking an external focus of attention might be superfluous for elite athletes because they already do so habitually (Schücker et al., 2015; Stoate et al., 2011). For instance during baseball pitching, the main task, throwing the ball at the pitchers mitt could already effect the actual attentional focus of the player. However, this explanation cannot account for the fact that pitching technique improved significantly in the internal focus of intention group compared to the external focus of intention group after the intervention cross-over (with the same tendency being present during the first intervention period). This effect is understandable in that the internal focus of intention instructions pertained to specific aspects of the technique, whereas external focus of intention instructions contain no information about these aspects by definition.

Second, it could be that the type of instruction they consistently receive from their coaches, often for years on end, has conditioned athletes. It is known, for instance, that the vast majority (about two-thirds) of the instructions given by coaches in (elite) sports focus attention internally rather than externally, not

only in baseball pitching (van der Graaff et al., 2017), but also in boxing and athletics (Halperin et al., 2016; Porter et al., 2010c). As a consequence, athletes might benefit more from instructions invoking an internal focus of attention compared to an external focus of attention, simply because they are more familiar with them (Weiss et al., 2008). As a result, the beneficial effect of external focus of attention found in experimental studies in which such ‘preconditioning’ is absent may be mitigated in studies with elite athletes such as the present one. Third, the pitchers who participated in the present study were elite athletes belonging to the best pitchers of their country and age category, implying that their skill level was already very high, making it much harder to improve pitching performance than in novice or recreational pitchers. It is therefore quite possible that the present study was limited by a ceiling effect and that even a longer training period than five weeks would have been required for performance improvements to become manifest and to differentiate between interventions in this regard. In anticipation of this possibility, we chose to conduct our intervention study at the beginning of the year, after the pitchers returned from a rest period, as we deemed this the most favorable period to bring about changes in pitching performance. Nevertheless, the observed progress in pitching performance was minimal.

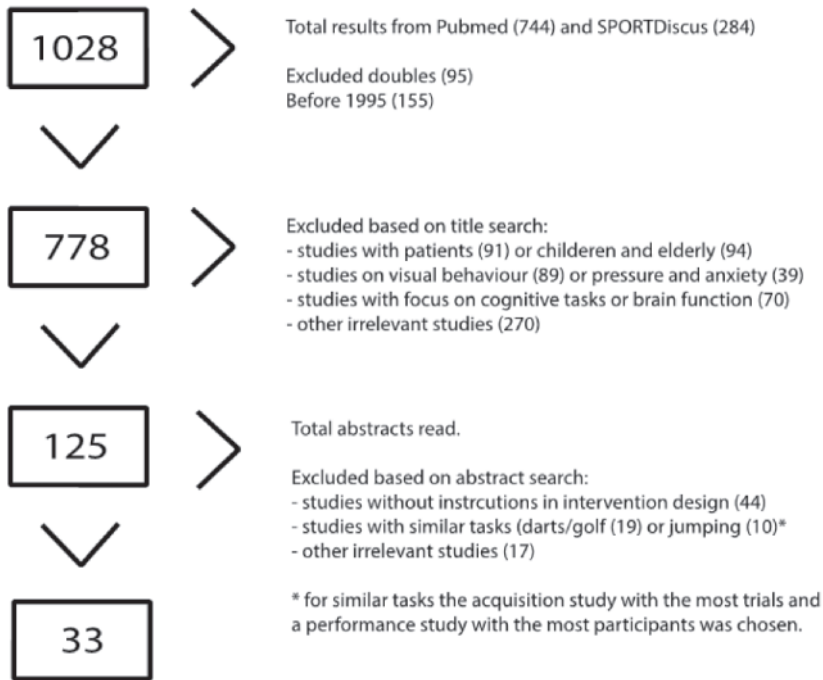
Finally, it may have been the case that significant main effects were not found in the present field study due to intrinsic methodological limitations. One crucial methodological limitation was the lack of control over the degree to which the coaches adhered to the type of instructions they were supposed to use in the various conditions, however, because the aim was to test the effect of those instructions in a regular environment, where players are being taught by their trainer, it is paramount that the actual coaches were giving the instructions, and not a researcher, or just instructions on paper. To get an idea of the magnitude of this problem, we analyzed randomly selected samples of the coaches’ instructions during the intervention and found that only 75-81% of the coaches’ instructions corresponded with the intended instructions. Although this degree of adherence to the prescribed instructions might be seen as an acceptable margin of error, as well as inevitable given the nature of the study, it renders the comparison of the effects of instruction type on performance development less clear-cut as desired.



Conclusion

In sum, during a five-week training period elite youth pitchers showed a similar development in pitching performance operationalized in terms of throwing velocity, accuracy and technique, which was largely independent of the type of instruction provided with the sole exception that pitching technique developed more favorably under internal focus of attention instructions. In light of previous studies we conclude that the beneficial effect of external focus of attention instructions cannot be simply generalized to day-to-day-training in an elite sports contexts. More research is needed to determine how external focus of attention instructions are best employed and implemented in an elite training program, at what stage and in which proportion to internal focus of attention instructions.

Appendix I: Systematic Review



Systematic review methods

A research librarian conducted a comprehensive literature search using the Pubmed and SPORTDiscus databases in order to find papers that studied the effect of using an external or internal focus of attention on the performance or the acquisition of an sports-like task. To do so, the following search items were used finding papers published up to August 2017.

Pubmed search (744 hits):

("Attention"[Mesh] OR focus of attention[tiab] OR attentional focus*[tiab] OR focused attention[tiab] OR focussed attention[tiab] OR attentional capture[tiab] OR sustained attention[tiab] OR attention span*[tiab] OR attention bias*[tiab] OR attentional bias*[tiab] OR external focus*[tiab] OR internal focus*[tiab] OR externally focus*[tiab] OR internally focus*[tiab] OR focus attention[tiab]) AND ("Psychomotor Performance"[Mesh] OR psychomotor performance*[tiab] OR motor performance*[tiab] OR task performance*[tiab] OR motor skill*[tiab] OR motor abilit*[tiab] OR motor acquisition*[tiab] OR psychomotor skill*[tiab] OR psychomotor abilit*[tiab] OR psychomotor acquisition*[tiab] OR motor



task*[tiab] OR motor learning[tiab] OR psychomotor learning[tiab] OR psychomotor task*[tiab] OR skill task*[tiab] OR "Reinforcement, Verbal"[Mesh] OR verbal reinforcement*[tiab] OR verbal instruction*[tiab] OR attentional instruction*[tiab] OR focus instruction*[tiab] OR focusing instruction*[tiab]) AND ("Sports"[Mesh:NoExp] OR "Athletic Performance"[Mesh] OR "Baseball"[Mesh] OR "Basketball"[Mesh] OR "Bicycling"[Mesh] OR "Soccer"[Mesh] OR "Football"[Mesh] OR "Volleyball"[Mesh] OR "Hockey"[Mesh] OR "Tennis"[Mesh] OR "Psychology, Sports"[Mesh] OR sport*[tiab] OR darts[tiab] OR swimm*[tiab] OR throw*[tiab] OR jump*[tiab] OR sprint*[tiab] OR volleyball*[tiab] OR taekwondo[tiab] OR tae kwon do[tiab] OR overhead[tiab] OR basketball*[tiab] OR baseball*[tiab] OR soccer[tiab] OR football*[tiab] OR handball*[tiab] OR softball*[tiab] OR hockey[tiab] OR tennis[tiab] OR kick*[tiab] OR punch*[tiab] OR agility[tiab] OR posture[tiab] OR postural[tiab] OR movement effect*[tiab])

SPORTDiscus search (284 hits):

(DE "ATTENTION" OR TI ("focus of attention" OR "attentional focus*" OR "focused attention" OR "focussed attention" OR "attentional capture" OR "sustained attention" OR "attention span*" OR "attention bias*" OR "attentional bias*" OR "external focus*" OR "internal focus*" OR "externally focus*" OR "internally focus*" OR "focus attention") OR AB ("focus of attention" OR "attentional focus*" OR "focused attention" OR "focussed attention" OR "attentional capture" OR "sustained attention" OR "attention span*" OR "attention bias*" OR "attentional bias*" OR "external focus*" OR "internal focus*" OR "externally focus*" OR "internally focus*" OR "focus attention")) AND (DE "PSYCHOLOGY of movement" OR DE "MOTOR ability" OR DE "MOTOR learning" OR DE "PERCEPTUAL-motor processes" OR DE "REINFORCEMENT (Psychology)" OR TI ("psychomotor performance*" OR "motor performance*" OR "task performance*" OR "motor skill*" OR "motor abilit*" OR "motor acquisition*" OR "psychomotor skill*" OR "psychomotor abilit*" OR "psychomotor acquisition*" OR "motor task*" OR "motor learning" OR "psychomotor learning" OR "psychomotor task*" OR "skill task*" OR "verbal reinforcement*" OR "verbal instruction*" OR "attentional instruction*" OR "focus instruction*" OR "focusing instruction*") OR AB ("psychomotor performance*" OR "motor performance*" OR "task performance*" OR "motor skill*" OR "motor abilit*" OR "motor acquisition*" OR "psychomotor skill*" OR "psychomotor abilit*" OR "psychomotor acquisition*" OR "motor task*" OR "motor learning" OR "psychomotor learning" OR "psychomotor task*" OR "skill task*" OR "verbal reinforcement*" OR "verbal instruction*" OR "attentional instruction*" OR "focus instruction*" OR "focusing instruction*")) AND (DE "SPORTS" OR DE "BASEBALL" OR DE "BASKETBALL" OR DE "CYCLING" OR DE "SOCCER" OR DE "FOOTBALL" OR DE "VOLLEYBALL" OR DE "BALL hockey" OR DE "FIELD hockey" OR DE "LAWN hockey" OR DE "TENNIS" OR DE "SPORTS psychology" OR TI (sport* OR darts OR swimm* OR

throw* OR jump* OR sprint* OR volleyball* OR taekwondo OR “tae kwon do” OR overhead OR basketball* OR baseball* OR soccer OR football* OR handball* OR softball* OR hockey OR tennis OR kick* OR punch* OR agility OR posture OR postural OR “movement effect*”) OR AB (sport* OR darts OR swimm* OR throw* OR jump* OR sprint* OR volleyball* OR taekwondo OR “tae kwon do” OR overhead OR basketball* OR baseball* OR soccer OR football* OR handball* OR softball* OR hockey OR tennis OR kick* OR punch* OR agility OR posture OR postural OR “movement effect*”))

Inclusion and exclusion criteria

First, doubles were excluded using EndNote (vX7.7.1, Thomas Reuters, Philadelphia, PA, USA). Second, papers from before 1995 were excluded. We considered the Wulf and Prinz (1997) paper the first paper that discussed internal and external focus learning in a sports-like context, and therefore did not expect to find additional papers in an earlier time frame.

Those two operations resulted in 778 titles. Those titles were scanned, to exclude studies using patients, elderly, or children under the age of twelve as participants. Furthermore, studies that did not investigate motor performance but visual attention, cognitive functions or other mental trades were excluded. After excluding all further irrelevant papers, a list of 125 papers eligible for review was formed.

Reviewing process

125 abstracts were reviewed to find studies that performed an intervention using external and internal focus of attention instructions in order to change the performance and/or the acquisition of a sport-like motor task. In case multiple papers investigated the same task, only the study with the most participants was given further consideration.

Outcome categorization

From each of the 33 eligible and included studies, the following information was extracted and collated in Table 1: the experience of the participants, the task under investigation, the nature of the study (lab or field), the number of trials and the study duration. In the table a distinction is made between *performance* studies – those that study the direct change of outcome effect of a specific task or skill by changing one’s focus of attention - and *acquisition* studies – those that study the change in outcome effects of a specific task or skill after training with different foci of attention.



Appendix II: 10 Keypoints

Keypoint:	Phase/body part	Description
1	Wind-up/leg	When squatting down, knee stays behind toe.
2	Wind-up/arm	Swing down, arm stays in line with the shoulders.
3	Wind-up/leg	Knee of stance leg rotates inward before foot plant.
4	Wind-up/arm	When swinging the arm up, hand moves above shoulder line before elbow.
5	Acceleration/ leg	Front foot points toward target at foot plant.
6	Acceleration/ arm	The elbow is at the same height as, or higher than the shoulder.
7	Release/leg	Knee is extended through ball release.
8	Release/ arm	Release point of the ball is in front of the front foot.
9	Follow through/arm	Thumb points down after ball release, when swinging down (pronation).
10	Follow through/legs	Trailing leg rotates over the line between stance leg and catcher.



Chapter 7

Enhancing pelvis and thorax rotation and throwing velocity in baseball pitching through technical feedback and instructions, with different foci of attention

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Abstract

Studies on the effectiveness of external and internal focus of attention instructions on motor performance and learning have concentrated on outcome measures and much less on movement execution itself. In the present study we compared the effects of external versus internal focus of attention, as well as technical feedback, on the development of outcome measures of pitching (i.e. throwing velocity and accuracy) and the acquisition of rotation velocity of pelvis and thorax using a between-subjects design. The pitchers underwent a two-day training intervention and a retention test a week later. No significant effects of instruction were found with regard to the outcome and movement measures of interest when comparing groups receiving external focus of attention instructions, internal focus of attention instructions and no instructions. This finding suggests that the alleged benefit of external focus of attention instructions might be limited in the context of elite sports. However, when technical feedback was provided in combination with internal focus of attention instructions, a significantly larger increase in maximum pelvis rotation velocity was found from the first to the second test compared to the group receiving internal focus of attention instructions only. Although this effect was short-lived, it suggests that technical feedback might be instrumental in adopting a (safe) movement technique. Future research is needed to determine if, and under what conditions, these effects can be long lasting.

Keywords: feedback, focus of attention, pitching, motor learning, biomechanics



Introduction

Athletes attempt to improve their performance through training, often with the help of a coach. Coaches, in turn, try to optimize training, ideally by applying evidence-based methods. Within the training environment, the coach typically aids this process by providing verbal instructions and (instrumental) feedback. Generally, performance enhancement is measured in terms of ‘faster, higher, stronger’ (*citius, altius, fortius*) outcome measures, but it can also be assessed by charting changes in the athletes’ skill level, as reflected, for instance, in the number of possibilities an athlete has available to achieve the desired outcome (Kelso, 2012; Mason et al., 2015; Orth et al., 2017). A relevant question from both a theoretical and practical point of view is how both performance and movement execution are trained and taught best via instruction and feedback. It can be expected that practice alone improves desired outcome outcomes, regardless of the additionally provided information. In complex athletic activities, such as baseball pitching, performance (i.e. throwing velocity and accuracy) is often optimized by means of training specific movement techniques that are part of the throwing motion. Biomechanical studies have provided empirical evidence for a number of movement techniques that need to be optimized to expect improved outcome effects. For instance, pelvis and thorax rotation velocity and the relative timing between them has been defined as critical elements in generating a high throwing velocity (SgROI et al., 2015; Urbin et al., 2013; van der Graaff et al., 2016).

One aspect of the instructions provided is how they affect the players’ focus of attention during training. A wealth of studies have shown that providing instructions that direct attention to the effect of the movement in the environment (external focus of attention), rather than the movement itself (internal focus of attention), are beneficial to both motor performance and learning (Wulf, 2007; Wulf et al., 2001c). The empirical support for this insight has mainly been obtained in studies involving students as research participants. To date, only a limited number of studies examined the potential benefits of using an external focus of attention in an (elite) athletes’ sport setting (for a systematic review see (van der Graaff et al., 2018)). An interesting question, therefore, is if athletes show similar beneficial effects from external focus of attention instructions in their regular training environment as has been (mainly) demonstrated in controlled environments with participants of low to moderate skill levels.

The effects of feedback on skill acquisition have been documented in a number of studies involving video feedback of the executed performance as feedback (Lauber et al., 2014). Since nowadays almost everybody possesses a mobile phone, providing high quality images at high frame rates, video feedback is often integrated in regular training practice. The use of technical feedback from wearable technology, however, has only recently made its appearance in

scientific studies of training interventions (Li et al., 2016). Technical feedback from wearables is a new and easy-to-use tool that can provide feedback on isolated movement skills. Wearable devices allow one to measure and document movement behaviour more accurately than with video. Furthermore, information of all activities during training can be stored and compared, which stands in contrast to recording and replaying only one or a number of movements on video. In the present study such a tool was used to provide (near) real-time feedback during bullpen training of baseball pitchers. The research question of interest was if real-time technical feedback based on wearable technology might be a beneficial tool to increase pitching performance. In addition, we sought to determine how this real-time feedback about the movement itself would compare to the expected benefits of providing instructions evoking an external focus of attention.

In order to study the differences between receiving no instructions, receiving instructions with an external focus of attention or instructions with an internal focus of attention on the development of throwing velocity and accuracy in baseball pitching and the development of peak rotation velocity of pelvis and thorax, a group of elite high-school baseball pitchers underwent a two-day training intervention with a retention test one week later. It was hypothesized that players receiving external focus of attention instructions would perform better than players receiving no instructions and players receiving internal focus of attention instructions. In addition to this first research question, we wondered what the differences would be between groups receiving technical feedback as well as internal focus of attention instructions and groups receiving only external focus of attention instructions, and what the additional effect would be of receiving technical feedback to receiving internal focus of attentions instructions. In particular, it was hypothesized that players receiving technical feedback together with internal focus of attention instructions would improve their performance more than players receiving only internal or external focus of attention instructions during training.

Methods

Participants

Thirty-seven male pitchers (age range 12-18 years) of the Dutch baseball academies, playing at the national instructional league for their respective age levels, were recruited to participate in the study during regular training sessions. All participants and their legal representatives were informed of the study's objectives and signed a consent form before the start of the study. The study was approved by the local ethical committee of the Department of Human Movement Sciences of the Vrije Universiteit Amsterdam under reference ECB 2013-53, and subsequently performed in accordance with the Declaration of Helsinki (World Medical, 2013).



Study design

The study consisted of three intervention days that spanned two weeks and was performed at the pitchers' regular (outdoor) training facilities during the pitchers' regular training time. Each intervention day consisted of a bullpen session of 35 pitches (figure 1) delivered from a mound to a catcher sitting at the regular game distance (18.3m). The number of 35 pitches on a single day (three times per week) is the maximum allowed pitch count for players of this age. The first and last four pitches of the bullpen sessions were designated as pre- and post-test measurements. The first four pitches on the third day were taken as retention test. Pitchers were not allowed to perform any throwing activities between the first and second intervention days. The throwing activities in the week between the second and third intervention days were not controlled. Typically, pitchers played three innings (which, on average, involves in the order of 35 pitches) in the weekend and trained on Monday, Tuesday and Wednesday in between, with a bullpen-session instructed by their regular coach on Tuesday.

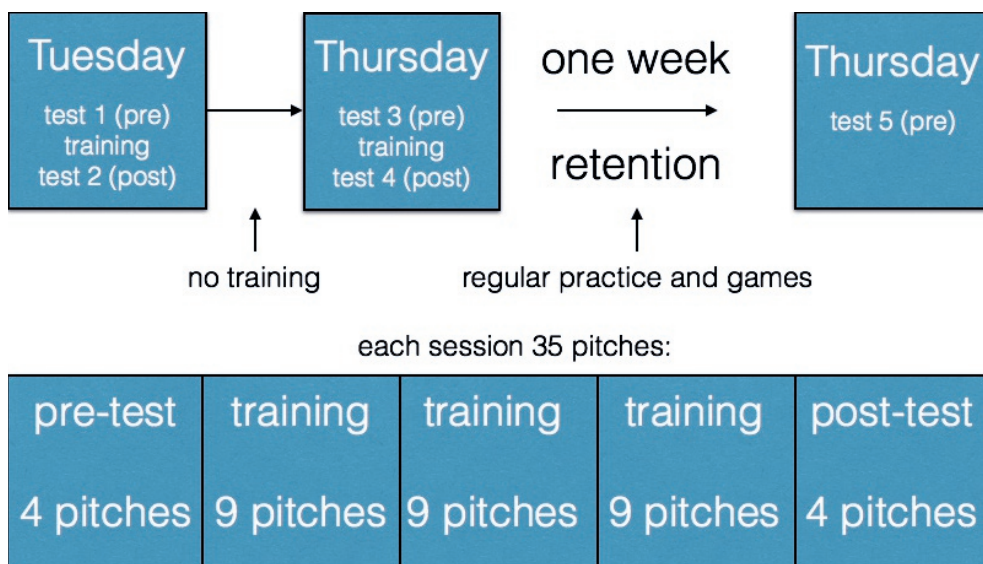


Figure 1 Study design

Experimental groups

Four experimental groups were formed to answer the research questions: (1) a control group, receiving no instruction or feedback, (2) an EF group, receiving only instructions evoking an external focus (EF), (3) an IF group receiving only instructions evoking an internal focus of attention (IF), and (4) an IF + F group receiving internal focus instructions (IF) combined with feedback (F) about

peak pelvis and thorax rotation velocity. The players were allocated to the four groups using a stratified randomization procedure, which accounted for age and resulted in equal group sizes. The experimental groups received instructions regarding their maximum pelvis and thorax rotation velocity and the time between the instances at which these maximum velocities occurred, called the time separation. Following the example of Wulf (Wulf et al., 2010a) internal and external focus instructions were designed to bring about the same movement effects (table 1). In addition to internal focus of attention instructions, the IF + F group received (near) real-time feedback about peak pelvis and thorax rotation maximum velocity and separation time via a laptop screen. On this screen the maximum rotation velocity of pelvis and thorax, and separation time was displayed after every pitch. The control group received neither instructions nor feedback.

Table 1 Instructions to evoke either an internal or external focus of attention.

<i>internal focus</i>	<i>external focus</i>
Rotate your hip as fast as possible.	Rotate the device on your hip as fast as possible towards the catcher.
Rotate your chest as fast as possible.	Rotate the device on your chest as fast as possible towards the catcher.
First rotate your hip and then your chest.	Make the distance between the devices as large as possible.

Procedure

Before each study day, the coach drew up a schedule at what time pitchers had to perform their bullpen session, which was performed two-by-two. Thirty minutes in advance of that time, pitchers performed their regular pre-bullpen warm-up. The general warming-up started with running exercises, and consisted of j-band exercises to warm up their arms. The general warm up was followed by a minimum of 10 minutes of long-toss and pull-down. After this throwing warm-up, pitchers were equipped with two rubber bands, one around their hips and one around their trunk. Both bands held a pocket in which an inertial measurement unit (IMU) (Shimmer3, Shimmer, Dublin, Ireland) was mounted. Pitchers were allowed to throw a maximum of 10 warm-up pitches on the mound before starting the training, allowing them to familiarize themselves with the experimental conditions.



Before the start of the bullpen session, it was explained that the participants were going to throw 35 pitches in 5 blocks, with 4 three-minute brakes in between (figure 1). They were instructed to pitch fastballs, as fast as possible, at the location indicated by the catcher. All players except the players in the control group were told that, while performing their training session, they had to read the instructions out loud every other pitch and try to execute the instructions as well as possible. All instructions were printed out on a sheet of paper, which was then plasticized and stored in a display map. Next, all players except the players in the feedback group were told that the IMU's measured rotation velocity of their hips and trunk, but that this measurement was only for research but not for training purposes. The players that received feedback were told that the IMU's were used to generate the information displayed on the laptop. Both the laptop and display map were placed besides the pitching mound. For the feedback group, the laptops were placed with the screen facing the pitcher. For the other groups and during the four-pitch tests, the laptops were placed close enough to ensure proper Bluetooth connection but with the screen facing away from the mound to prevent players from looking at them. Before the four-pitch tests, the players only were reminded of the main task; 'throw four fastball pitches at maximum throwing speed aimed at the requested location' and received no further feedback or instructions (figure 2).

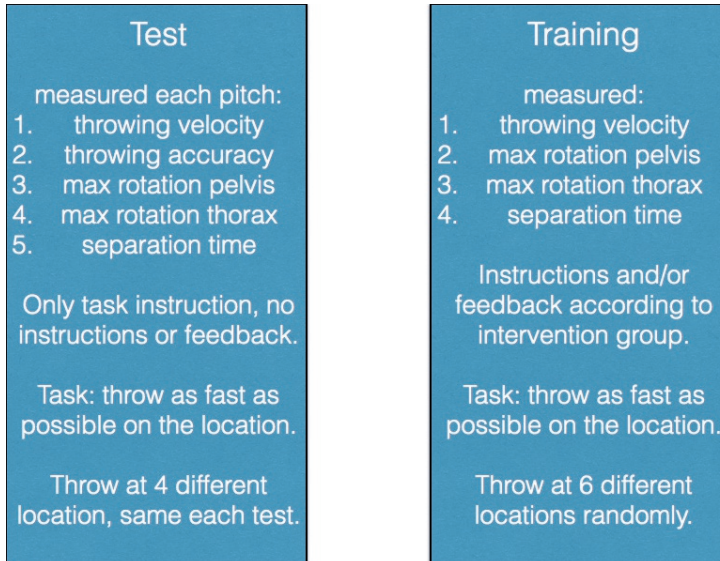


Figure 2 Test and training procedure.

Data acquisition and analyses

Throwing velocity was recorded with a radar gun (Stalker Pro II, Applied Concepts, Inc./Stalker Radar, Richardson, Texas, USA). To assess throwing accuracy, the catcher was recorded with a high-speed video from the mound during the test. Each pitch had to be aimed at one of six locations as indicated on the target sheet (figure 3). The order in which the target locations were presented, which was randomly generated by a computer, was fixed for all tests and specified to the pitcher by the catcher. The actual pitch location was determined as the position at which the ball hit the catchers' mitt and this location was compared to the requested location. For an exact agreement between the target and actual location a player received 2 points, while for a 'near hit', a hit in a box next to the targeted location, 1 point was scored.

Pelvis and thorax rotation velocity were measured using IMU's that were wirelessly connected to a laptop via Bluetooth. The incoming data stream was handled in real time with a custom-made Matlab program. The maximal pelvis and thorax rotation velocity during pitching was identified with an algorithm. The maximal pelvis and thorax rotation velocities were stored in separate matrices and displayed on the screen. From each four-pitch test the maxima of pelvis and thorax rotation velocity and the time between these maxima were preserved for further statistical comparison.

Following each test, pitchers answered two questions about their focus of attention, namely "What did you focus on during the last four throws?", and "What was the most important goal you tried to achieve during the last four pitches?" If the answer reflected an internal focus of attention a score of -100 was given, and if it reflected an external focus of attention a score of +100 was given; if neither an internal or external focus could be distilled from the answer, a score of 0 was given. An average score was calculated for each participant and for each test. This individual average was used to calculate the direction of the focus of attention (negative, more internal / positive, more external) for each experimental group.



Figure 3 Target sheet with six possible throwing locations as used during the bullpen sessions. The strike zone (inner 3 × 3 zone) was 45 cm wide and 55 cm high. In official games, the width of the strike zone is 17 inches (43.18 cm), with the batter's body height determining the height of the strike zone.



Statistical analyses

To examine the effects of instruction and feedback on the development of throwing velocity and accuracy, and the maximal rotation velocity of pelvis and thorax, change scores for each outcome variable for the first day [results test2 - test1], the intervention period [results test4 - test1], and the retention period [test 5 - test 1] were calculated.

First, three independent t-tests, with a Tukey correction to account for family-wise error, were performed to identify any significant differences between the control group (receiving no instruction or feedback), the IF group and the EF group. Subsequently, to more specifically study the combined effect of instruction and feedback, planned Helmert contrasts (Field et al., 2010) were employed in two steps. First, the difference between the EF group and the IF and IF + F group combined, i.e. the two groups receiving feedback and/or instructions promoting an internal focus of attention, was examined. Next, the difference between the IF group and the IF + F was examined, in order to assess the effect of feedback alone (figure 4).

Analyses scheme

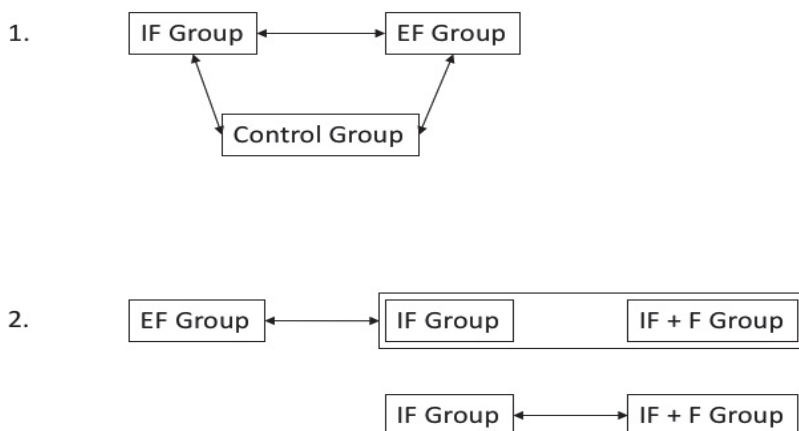


Figure 4 Visualization of the comparisons made with the two statistical models: 1. Three comparisons involving independent t-tests. 2. Two comparisons involving planned Helmert contrasts.

Instructions and feedback were expected to affect outcome and skill in one direction, namely improved performance. Therefore, one-tailed tests were performed and the 90% confidence interval (CI) for each of the differences was calculated. Hedges' g was calculated as a measure of effect size. The effect was qualified as small for a value of Hedges' g below 0.5, as medium for values between 0.5 and 0.8, and as large for values of Hedges' g larger than 0.8 (Cohen, 1992). All statistical analyses were performed using SPSS (v 24.0.0.2, IBM Corporation, Armonk, NY, USA).

Results

Of the 37 pitchers, 36 pitchers completed the first day. However, due to a variety of reasons, only 21 pitchers completed all measurements. Participants dropped out due to injuries, school exams, and selection for national team games in between training days. Also one retention test had to be cancelled midway due to a thunderstorm.

At the first intervention day, from test1 to test2, throwing velocity increased from 30.6 m/s to 30.9 m/s (68.5 to 69.1 mph, $p=0.035$), independent of group. Peak pelvis rotation velocity increased on the first day with 58°/s, from 716°/s to 774°/s ($p=0.011$). Throwing accuracy (3.7 at test1) and peak thorax rotation velocity (1129°/s at test1) did not change significantly over groups.

Independent of group, from the first to fourth test or from the first to fifth test, no significant changes were observed other than for throwing velocity, which was on average 0.59 m/s (1.32 mph) lower ($p=0.016$) (i.e. of the pitchers that completed the intervention).



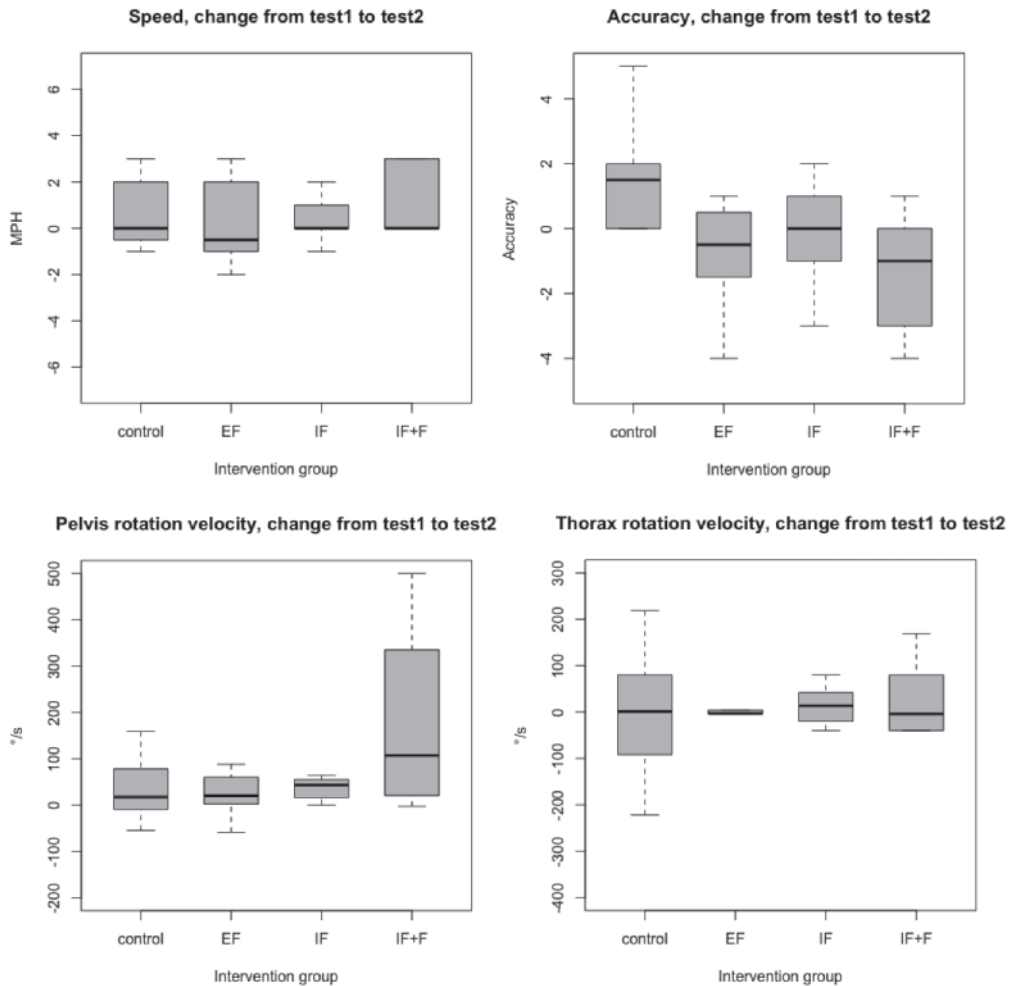


Figure 5 A/B/C/D a) top left, throwing velocity, b) top right, throwing accuracy, c) bottom left, peak pelvis rotation velocity, d) bottom right, peak thorax rotation velocity. Box-plots of the change from test1 to test2 for the four experimental groups: control group, EF = external focus group, IF = internal focus group, IF + F internal focus with feedback group.

Effects of instruction

The independent t-tests comparing the EF group and the IF group showed no significant differences between groups in progress from test1 to test2 (Figure 5), neither from test1 to test 4, nor from test1 to test5 between groups for the four outcome measures. However, one strong effect size (Hedges' $g = 1.06$) was

observed in the development of the maximum pelvis rotation velocity between test1 and test 4 in favour of the IF group (Table 2). The independent t-tests comparing the EF group and the control group and comparing the IF group and the control group showed no significant differences in progress between any tests for the four outcome measures.

Table 2 Effect sizes (Hedges' g) of the independent t-test comparisons between the control, EF and IF group, for all the four outcome measures, of the change from test1 to test2, test1 to test4, and test1 to test5.

development(Δ) between:	outcome measure	comparison between		
		IF-EF	EF-control	IF-control
Δ test2 - test1	Velocity	0.29	0.38	0.12
	Accuracy	-0.01	0.48	0.58
	Pelvis	-0.49	0.26	-0.24
	Thorax	-0.2	0.21	0.05
Δ test4 - test1	Velocity	0.13	0.13	0.28
	Accuracy	0.08	0.36	0.53
	Pelvis	1.06	-0.77	0.12
	Thorax	0.12	1.01	0.93
Δ test5 - test1	Velocity	0.16	-0.50	-0.33
	Accuracy	0.03	0.13	0.19
	Pelvis	-0.48	0.49	-0.01
	Thorax	0.41	-0.06	0.26

Effects of instruction and feedback

Contrast between EF and IF & IF+F group

Between test1 and test2 mean change of the IF & IF+F group combined in peak pelvis rotation velocity ($M = 100^\circ/s$, $SD=159^\circ/s$) was significantly different from the mean change in maximum pelvis rotation velocity in the EF group ($M=22^\circ/s$, $SD=47^\circ/s$)(figure 4). This significant difference between groups ($78^\circ/s$ $p=0.079$) had a medium effect size (Hedges' $g = 0.63$). The other outcome measures did not develop significantly differently when comparing the EF group with the IF&IF+F group between test1 and test2 (Table 3 and Figure 5). Between test1 and test4 and between test1 and test5 no significant differences were found in the development between the EF group and the IF&IF+F group for any of the four outcome measures (Table 3).



Contrast between IF and IF+F group

From the first to the second test, the mean change in peak pelvis rotation velocity of the IF+F group (M = 178°/s, SD=227°/s) was significantly different from the mean change in peak pelvis rotation velocity of the IF group (M=57°/s, SD=93°/s). This significant difference between groups (121°/s p=0.099) had a large effect size (Hedges' g = 0.82). The other outcome measures did not develop significantly different when comparing the IF group with the IF+F group between test1 and test2 (Table 3 and Figure 5).

Between test1 and test4 no significant differences were found in the development between the IF group and the IF+F group for any of the four outcome measures (Table 3)

From the first to the fifth (retention) test, mean change of the IF+F group with feedback in throwing velocity (M=-3.4 mph, SD=2.8 mph) was significantly less from the mean change in throwing of IF group (M=-0.31 m/s, SD=1.07 m/s). This difference between groups (1.21 m/s p=0.091) had a large effect size (Hedges' g =-1.05). The other outcome measures did not develop significantly different when comparing the IF group with the IF+F group between test1 and test5 (Table 3 and Figure 5).

Table 3 90% CI of the mean difference of the two planned contrasts, for all the four outcome measures, of the change from test1 to test2, test1 to test4, and test1 to test5 with *p*-values, and effect sizes calculated as Hedges' g.

development(Δ) between:	outcome measure	comparison between			
		EF group - (IF group & IF+F group)			
		90% CI		<i>p</i>	Hedges' g
Δ test2 - test1	Velocity	-1.832	0.943	0.31	0.39
	Accuracy	-1.123	2.178	0.567	-0.19
	Pelvis	-177	-14	0.079	0.63
	Thorax	-114	69	0.644	0.19
Δ test4 - test1	Velocity	-1.545	2.695	0.617	-0.25
	Accuracy	-0.49	3.19	0.224	-0.62
	Pelvis	-70	119	0.601	-0.31
	Thorax	-57	122	0.414	-0.47
Δ test5 - test1	Velocity	-0.275	3.77	0.17	-0.55
	Accuracy	-1.273	2.116	0.675	-0.29
	Pelvis	-167	75	0.465	0.48
	Thorax	-146	188	0.814	-0.17

		comparison between			
		IF group - IF+F group			
		90% CI		<i>p</i>	Hedges' <i>g</i>
Δ test2 - test1	Velocity	-1.832	0.943	0.6	0.29
	Accuracy	-0.862	3.084	0.317	-0.65
	Pelvis	-231	-11	0.099	0.82
	Thorax	-124	113	0.93	0.05
Δ test4 - test1	Velocity	-2.635	3.535	0.788	-0.32
	Accuracy	-0.377	4.977	0.158	-1.16
	Pelvis	-261	42	0.16	1.33
	Thorax	-85	177	0.429	-1.03
Δ test5 - test1	Velocity	0.205	5.262	0.091	-1.05
	Accuracy	-1.419	2.819	0.578	-0.24
	Pelvis	137	185	0.773	-0.17
	Thorax	-336	127	0.413	0.48

Discussion

Effect of instructions

The present results neither showed significant differences between the experimental groups receiving either external or internal focus instructions, nor between these groups and the control group receiving no instruction. Although after the first intervention day an increase in throwing velocity and maximum pelvis rotation velocity was observed, this increase was similar over groups. These results stand in contrast with our hypothesis that external focus of instructions would be beneficial to performance, as has been found in a great number of previous studies involving students or other less skilled participants (Wulf, 2007). However, the present results are consistent with those from a subset of studies involving elite athletes (Halperin et al., 2017; Ille et al., 2013; Makaruk et al., 2013; Stoate et al., 2011). Stoate et al. (Stoate et al., 2011) explained the difference between students (novices) and athletes (experts) by arguing that for elite athletes external focus of attention instructions are superfluous when trying to achieve sport-specific outcomes. Weiss et al. (Weiss et al., 2008) offered an alternative explanation by arguing that switching to an unfamiliar focus might not be beneficial to overall performance, regardless of whether one is an expert or not (Weiss et al., 2008). However, this argument might hold specifically for elite athletes because they train many hours, mostly



with the same coach, and thus are repeatedly receiving the same type of instruction. For a variety of sports, including baseball pitching (van der Graaff et al., 2018), it has been shown that athletes typically receive instructions with an internal focus of attention (Halperin et al., 2017). Hence, to the extent that the argument of Weiss et al. (2009) holds, elite athletes thus do not benefit (or less) from instructions evoking an external focus of attention. A third explanation why no changes in performance measures were observed in the present study resides in the possibility of a ceiling effect in that the actual performance level of the participating athletes left little room for further improvement. Most studies comparing the effectiveness of external versus internal focus of attention instructions in elite athletes only concentrated on outcome measures and not on (changes in) movement execution or coordination (Halperin et al., 2017; Ille et al., 2013; Makaruk et al., 2013; Stoate et al., 2011). This is unfortunate because, besides outcome improvements, instruction-based interventions may also prompt athletes to explore and adopt new ways of movement execution to achieve a desired outcome, which could elevate their skill level. Diversity in movement execution to achieve a given desired outcome could also be important in the prevention of musculoskeletal injuries (Fleisig et al., 1995) and in both sports and rehabilitation (Kal et al., 2016b). However, the instruction manipulations in the present study neither affected outcome nor execution parameters.

Effect of instructions and feedback

The second aim of the present study was to examine the effect of feedback on the outcome measures. It was hypothesized that feedback combined with internal focus of attention instructions evoking focus would enhance performance compared to receiving only instructions and no feedback. Although there were no significant differences in the development of velocity and accuracy between groups, the IF+F group demonstrated a 27% (+178°/s) increase in maximum pelvis rotation after the first session. This group increased their maximum pelvis rotation velocity more than the IF group (the group with only instructions and no feedback), while the latter group increased their maximum pelvis rotation velocity more than the EF group. Although a significant effect with a large effect size (Hedges' $g = 0.82$) was observed for the development of maximum pelvis rotation velocity between the feedback and no feedback group, no significant effect was observed for the maximum thorax rotation velocity. Future research should determine how task-specific this beneficial real-time feedback is. To our knowledge this is one of the first studies using wearable technology to provide (near) real-time feedback during a training intervention in youth elite sports. Such feedback might be useful for skill development but also for injury prevention. However, studies over a longer time must indicate if retention effects show the same effect sizes as found in the present study,

and thus if feedback indeed should structurally be integrated in professional baseball training practice.

Limitations and recommendations

The present field study suffered from a major limitation. Even though we worked with athletes that were part of a national program, and were thus obligated to attend training sessions, a considerable dropout of participants (i.e. from 37 to 21 participants) occurred due to a variety of reasons. For one, a test day had to be cancelled half way due to weather conditions. It might be argued that due to the dropout the current study lacked sufficient power to find differences between the training interventions. On the other hand, however, the wide range of drop out reasons probably ensured that this drop out was random and did not have an effect on the observed effects and effect sizes, some of which were still significant and noteworthy to report. Based on the experience of the present study, it might be recommended to include even a larger number of participants than would be necessary to reach statistical power, in order to account, in advance, for possible unforeseen drop out. However, in the context of elite sports large numbers of participants are by definition less easy to come by than in (lab) studies with ordinarily skilled participants.

Conclusion

Performance development in elite pitchers during training was found to be independent of instruction and instruction type (i.e. external versus internal focus of attention instructions). However, when combined with real-time technical feedback internal focus of attention instructions led to significant improvements in maximum pelvis rotation velocity with medium to large effect sizes. Thus, it appears that movement-related feedback may help to enhance the adoption of a (safe) movement technique, albeit that in the present study this effect was short-lived. Future research is needed to determine if, and under what conditions, these effects can be long(er) lasting.



Appendix 1

Direction of the focus of attention as scored through the questionnaires, for each of the experimental groups. Answers were scored -100 when they would evoke an internal focus of attention, and +100 if the answers would indicate an external focus of attention. The most answered question demonstrated an external focus of attention and was; 'I focus on hitting the target (with the ball)'. A one-way ANOVA was performed to study the differences in focus of attention between experimental groups ($F(3,30)=4.041$ $p=0.016$). Bonferroni post hoc testing demonstrated that the control group had a more external focus of attention than both internal focus of attention groups (with and without feedback). The external focus group did not significantly differ from any group (because of the large standard deviation within the group). Also both internal focus of attention groups (with and without feedback) did not significantly differ from each other in the general direction of focus of attention.

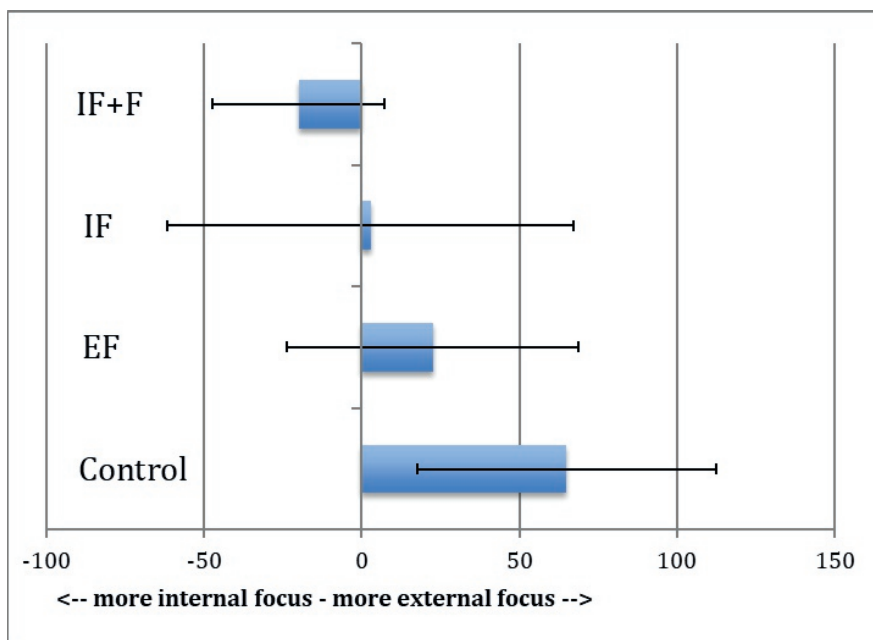


Figure 6 Group mean and SD for the general direction of focus of attention of the four experimental groups.



Chapter 8

Epilogue

The overarching aim of the work presented in this thesis was to gain a better understanding of fast and safe throwing in baseball and how to effectively train elite youth baseball pitchers through instruction and feedback. In the first part of the thesis, kinematic characteristics of the pitching motion were examined in relation to throwing velocity. **Chapter 2** focused on the timing between the moments of peak rotation velocity of the pelvis and the thorax. It was found that the inter-segmental timing between pelvis and thorax is associated with throwing velocity, whereas the maximal rotation velocity of the individual segments was not. This finding was especially noteworthy as the study in question was performed in a homogeneous group of young elite pitchers; within this group the inter-segmental timing proved to be a predictor of throwing velocity. Besides being an interesting finding from a biomechanical point of view, this result also opens the door towards an online feedback application aimed at training the kinematic chain as a whole. Furthermore, in the first part of the thesis, two studies were presented that focused on a individual joints parameters. **Chapter 3** showed that, in young elite pitchers, extending the knee was related to higher throwing velocity. Using a generalized estimated equation a small significant positive effect was found, involving a range of body types. This finding can be implemented in both flat-ground throwing and pitching from a mound. **Chapter 4** examined the difference in upward scapula rotation between the dominant and non-dominant arm of young elite pitchers and the evolution of scapular upward rotation during a one-year period. On average, an asymmetry of more than 5° upward scapula rotation was found between the dominant and non-dominant arm. This deviation might be related to the development of shoulder injuries. The asymmetry was displayed in both a younger and older age group and did not change during the one-year study period.

In the second part of the thesis, the use of external focus of attention instructions in elite baseball training was evaluated. First, verbal statements of six coaches were recorded during four training sessions in an observational study (**chapter 5**). Analysis of these statements revealed that the coaches gave twice as many instructions that invoked an internal focus of attention than instructions invoking an external focus of attention. The difference in acquisition between instructions evoking an internal and external focus of attention was examined, but no differences between performance parameters after a five-week training period were found (**chapter 6**). The additional effect of sensory feedback on performance in elite youth baseball pitchers was studied in **chapter 7** and it was found that, on a group level, instructions focussing on the movement itself in combination with (near) real-time feedback improved movement behaviour in a single training session. Additional feedback therefore seems a useful tool in bringing about changes in movement behaviour since some of the short-term effects had a large effect size, although long-lasting effects were not observed.



Optimal pitching performance

The main objective of the first part of this thesis – optimal pitching performance – was to obtain a better understanding of the cohesion between the individual body segments of the kinematic chain. Like in previous group studies (Sgroi et al., 2015, Urbin et al., 2013) **chapter 2** it was found that the timing between pelvis and thorax rotation is associated with throwing velocity. However, in the present study, this association was also found within pitchers, and accounted for the changes from preseason to midseason. The strong association between the *change* in separation time and the *change* in throwing velocity found in this small and homogeneous group suggests that there is a causal relationship between the two. If so, it would be useful to provide feedback on the timing between segments in training the kinematic chain and thus pitching with the body as a whole. This could potentially lead to new training protocols for elite athletes aimed at achieving higher throwing velocities.

In the course of the present project, some other studies have focussed on inter-segmental timing in pitching as well (Sgroi et al., 2015, Urbin et al., 2013). However, those studies used a marker set-up based on the plug-in-gait model and not the ISB recommended model for calculating thorax rotations. This difference might have had an effect on the estimated time of occurrence of thorax peak rotation velocity, which in turn could have influenced the estimated separation time. It is recommended in future work to calculate ‘pure’ thorax rotation velocity and not a mixture of thorax rotation, scapular rotation and shoulder pro- and retraction (Gasparutto, 2018). Also, future work should further evaluate the timing between peak rotation velocities of upper and lower arm, and of the lower arm and hand. Obtaining more detailed information about the timing between the thorax and upper arm may provide further insight into the working of the shoulder complex. However, the shoulder consists of multiple joints and is extremely difficult to track in vivo, especially under high-speed conditions, which makes it very hard to measure the power flow through the different segments of the shoulder. As demonstrated **in chapter 4**, the characteristics of basic scapula kinematics are already different between the dominant and non-dominant arm of a pitcher; the same is likely to hold for kinematic and kinetic measures obtained during throwing. To understand the interactions within the shoulder complex of a throwing athlete, the dominant (throwing) arm needs to be studied further, preferably with a measurement system that is capable of measuring inter-segmental timing. The feedback system used in **chapter 7** could perhaps be integrated with a sensor on the acromion to measure the motion of the shoulder girdle and scapula (Cutti et al., 2009; Kontaxis et al., 2009; Parel et al., 2012; Scibek et al., 2014). To facilitate such measurements, smaller sensors with less weight than currently (commercially) available need to be developed.

Another aim of part one of the thesis was to further pinpoint the biomechanical factors that are associated with high velocity pitching. Results of our studies were largely in agreement with those of previous studies. Increasing rotation velocities, larger step length and an extending knee after foot plant of the stride leg all indeed seem essential in order to achieve high throwing velocities during pitching. The factors that were studied in the present thesis, in combination with some factors that are generally seen as important for high velocity pitching by expert coaches, were summarized in a playbook with 10 key points of pitching (see Appendix II of **chapter 6**). The playbook provides a practical guideline that can be used in day-to-day pitching practice by pitching coaches. It is generally believed that a proper technique not only contributes to high throwing velocities, but would also help to prevent injuries. In a study focussing on upper extremity load in a homogeneous group of elite youth pitchers (Gasparutto et al., 2016), it was found that elbow load was related to elbow flexion but not to throwing velocity. Thus, the load can be to some extent modified (i.e. decreased) by changing the elbow angle, without a significant loss of throwing velocity. This finding provides additional evidence for the suggestion that that teaching the proper throwing technique can potentially decrease the injury risk by reducing (or redistributing) joint loads (Davis et al., 2009; Fleisig et al., 1999a; Fleisig et al., 2009).



Figure 1 *Extending the knee from MER-BR is associated to higher throwing velocity.*

Optimal pitching training

The aim of the second part of the thesis – optimal pitching training – was to improve pitching training by determining the role of instructions and feedback. In particular, the role of instructions, evoking either an internal or external focus of attention, was studied in detail. As a first step in this process, the instructions of each of the coaches of the six Dutch academies were recorded during four



training sessions. It was found that the baseball coaches mainly referred to the movement itself when they instructed their players during training. Although numerous studies have provided empirical evidence that performance improves under external focus of attention conditions, the findings of **chapter 5** revealed that this insight has not (at all) found its way to sport practice. This was not only found to be the case in baseball, but also in track and field (Porter et al., 2010c) and boxing (Halperin et al., 2016), where coaches hardly use instructions that evoke an external focus of attention. However, the percentage of external cues presented in **chapter 5** was higher than in the other two studies. This might be explained by the fact that external cues are more readily available in baseball than in, for instance, track-and-field.

Based on the results of **chapter 5**, a clear need became apparent to further develop and test the use of external focus of attention instructions during pitching training. To this end, an intervention study was designed to compare the effectiveness of instructions evoking either an external focus of attention or an internal focus of attention over a longer time span, in a training setting dedicated to pitching. For all of the 10 biomechanical key points from the playbook, exercises and instructions were created that provoked either an internal and external focus of attention. Next, a randomized controlled study with 45 baseball pitchers from the national youth teams of the Netherlands, Belgium, Germany and Italy was conducted comparing the effectiveness of these instructions in regular training settings covering a 5-week training period (**chapter 6**). Pitching performance was found largely independent of the type of instruction provided. No differences in the velocity and accuracy of pitching between the internal and external focus of attention groups were found.

In extant literature, has been the general consensus that under external focus of attention conditions development improves favourably compared to an internal focus of attention. However, after detailed study of previous 'acquisition' studies (Table X1, Introduction) it might be fair to say that evidence for this is indistinct at best. A study on landing technique by Benjaminse et al. (Benjaminse et al., 2015) showed only progress for the female participants under the external focus condition and not for the male participants. A study by Woo, Yi and Koh (Woo et al., 2014) only found in one of many outcome measures a preferred development under external focus conditions. Furthermore, van Abswoude et al. (van Abswoude et al., 2018) recently published a replication of an earlier study by Wulf et al. (Wulf et al., 2001a). In both studies, participants under external focus of attention conditions performed overall better than the participant under internal focus of attention conditions. However, no significant interaction between intervention and session was found implying there was no difference in skill *acquisition* between groups. Based on the literature review presented in this thesis, and the empirical findings reported in **chapter 6 and 7**, we conclude that, at least for elite athletes, external focus of attention instructions are likely

not superior to internal focus of instructions in the training of baseball pitch training, although, admittedly, no full-blown acquisition study was performed to further substantiate this conclusion.

The current thesis was part of the research project 'project FASTBALL'. In this project coaches of the Dutch national academies (**chapter 5 and 7**) and European youth teams (chapter 6) worked closely together. This cooperation, which is currently continued in the Baseball Science Centre NL, not only contributed to the internal validity of the thesis, but also to its potential practical value, that is, to its external and ecological validity. To achieve this high ecological validity, the studies presented in this thesis (**chapter 5,6,7**) were performed in the day-to-day practice of the best youth baseball players of the Netherlands and Europe. It might be argued that, compared to more lab-based studies involving less talented subjects, there was less 'room' for instructions evoking an external focus of attention to improve performance since pitching performance was already at a high and presumably highly automatized level. Furthermore, it might well be that athletes familiarize themselves with the type of instruction they usually receive, making those instructions more effective than unfamiliar instructions of in (Maurer et al., 2013). As became apparent in **chapter 5**, baseball players are more familiar with internal focus of attention than with external focus of attention instructions, rendering the latter less effective. Beilock et al. (Beilock et al., 2002) even demonstrated a negative performance effect of external focus instruction in elite soccer dribblers. Likewise, in **chapter 6** it was found that after training for five weeks under external focus conditions, the score on pitching technique decreased, possibly because any instruction would de-automatize the control of these players. In line with these results, Stoate and Wulf (Stoate et al., 2011) concluded in an experiment with elite swimmers that external focus instructions were superfluous. In the light of these findings of the interventions with elite athletes, the outcomes of the studies presented in **chapter 6 and 7** are not so unexpected and might explain that the players in **chapter 6** improved throwing techniques more under internal focus conditions, especially when combined with technical feedback (**chapter 7**). In a similar vein, the effectiveness of translating instructions to other environments where they are not commonly used has been criticized in the context of rehabilitation (Kakebeeke et al., 2013).

The empirical evidence from 'performance' studies can, however, not be ignored outright (Table X1, Introduction). In baseball specifically, there are many tasks that are already 'external' in nature that can be easily used in regular practice. 'Hit the catcher's mitt', 'curve the ball', 'step of the plate' are just some examples. In future studies, it would therefore be of interest to study the development of pitching performance over a very long period, and to have pitchers that have been familiarized to solely one type of focus of attention instruction. Usually the road to a national team is that players are very good in

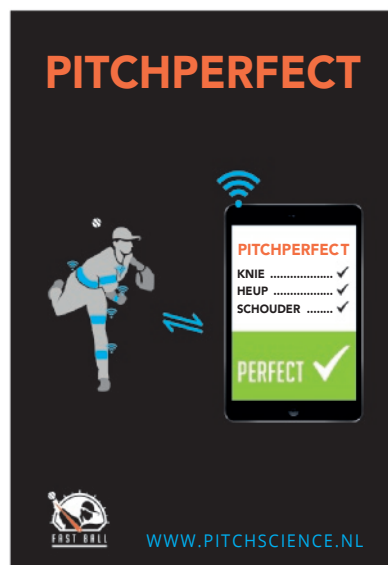


performing what the coach (explicitly) wants to see. They have become good in those movements because they are good in performing the instructed motion with the typical (internal) instruction style of the coaches. It could be that the empirical evidence that has been found up to this day, indicating that external focus of attention instructions are superfluous for elite athletes, is heavily influenced by this selection bias. It would be of interest to study a group of elite athletes, and perform a similar study as is performed in **chapter 6**, with players that always received external focus of attention instructions. Although in a (elite) sport setting it will probably be difficult to create a (scientifically) controlled environment for such a long period, and against the existing instruction culture.

In addition to the instruction of coaches, the added potential of individualized, near-real time, technical feedback during training was studied in **chapter 7**. Technical feedback can aid three aspects that have been neglected before. First of all, the feedback is individualized, providing progress benchmarks that are customized to each individual's technique. It has been suggested before that frequent feedback aids performance execution (Wulf et al., 1998b). Furthermore, feedback was found to be most effective when the athlete can self-regulate the intake of that feedback (Chiviacowsky et al., 2012). With the pitch-to-pitch feedback system, presented in **chapter 7**, feedback is available every pitch, and a pitcher can look at the feedback at any time he pleases. In a situation without such a device, the frequency of feedback is dependent on the availability of the coach, who most of the time has to take care of 10-20 other players at the same time. Moreover, coaches usually give feedback when something went wrong, even though evidence exist that positive reinforcement is more effective (Mouratidis et al., 2008). Second, the multiple sensor system provides feedback on timing between segments. Giving automated feedback about inter-segmental timing introduces feedback to address the serial-order problem. Next to the importance of a full-body approach in teaching pitching, this feedback system has the added value that the sequential rotation of the segments can be quantified and reported, which is very hard to do with the naked eye. Third, the onset of fatigue and injury can potentially be distilled from the data that are stored during the use of a (feedback) system that measures every pitch. Apart from the feedback, collecting movement data from players can also serve as an individualized database. The role that these individualised databases can play, and their impact on motor learning, injury prevention, and fatigue, will be major themes in future research.

With the current technology, a (near) real-time feedback system based on IMU sensors was developed. In recent years a number of single sensor systems have appeared on the market and in science (Makhni et al., 2018), but to date only single sensor systems are commercially available, which thus lack the capability to measure inter-segmental timing. Therefore, a multiple sensor system was developed (see **chapter 7**) in order to provide feedback about

thorax and pelvis rotation velocity and their relative timing. The feedback was color-coded to indicate performance based on group averages for the players' respective ages. Future hardware development and accompanying software will be instrumental in further expanding the system. First, development of faster IMU's should provide the possibility to measure kinematics and timing of the arm segments. At the moment, the commercially available accelerometers in the IMU's (up to $4000^\circ/\text{s}$) are not fast enough to keep up with the extreme rotational velocities achieved during pitching (up to $8000^\circ/\text{s}$). At the same time, these IMU's need to become smaller and lighter in order not to interfere with regular kinematics of the arm; this can be achieved if stronger and lighter batteries and Wi-Fi transmitters become commercially available. Development of this technical equipment is mostly pushed by the commercial mobile phone industry and not by academic necessity. If small sensors with strong transmitters can be incorporated in tight clothes, it could even become feasible to measure during games, without any impediment for the athlete. It has been suggested that game pressure, fatigue and the changing tasks during a match can influence performance, and with these techniques it would become possible to accurately collect a whole new set of potentially important data. If large quantities of data can be collected during training and games, rich databases can be developed, detailing different levels of performance and physical characteristics. In all likelihood, this will lead to a better and more encompassing understanding of full-body kinematics and the power-flow for each athlete. In addition, these databases would provide optimized training schedules, assist coaches on the field, empower trainers and medical staff with detailed individualized information, and thus aid each athlete to throw faster while keeping the risk of injury at bay.



Conclusions

1. The relative timing of pelvis and thorax peak rotation velocity in pitching fastballs in baseball is likely to be associated with throwing velocity.
2. Stride length and knee angle at the moment of shoulder maximal external rotation and ball release are associated with a higher ball speed.
3. The dominant arm of youth baseball pitchers displays more scapular



upward rotation than the non-dominant arm. Scapular upward rotation seems similar between older and younger pitchers and does not increase over time.

4. Pitching coaches mainly employ internal focus of attention instructions, i.e. instructions that direct attention at the movement itself. Likewise, pitchers mainly report to use internal focus of attention instructions when seeking to improve their performance through training.
5. The development of pitching performance in elite youth pitchers, operationalized in terms of throwing velocity, accuracy and technique, is largely independent of the type of instruction provided.
6. Internal focus of attention instructions in combination with real-time technical feedback seems a promising method to enhance adoption of a (safe) movement technique.

Recommendations for future studies

1. To examine inter-segmental timing during pitching of all other segments than pelvis and trunk in relation to throwing velocity.
2. Determine the effect of variations in inter-segmental timing on joint load and joint power, so as to determine critical instances in the pitching motion to decrease injury risk.
3. Determine the effect of instructions evoking either an internal or external focus to which elite athletes are familiarized before the intervention and the effect of those instructions on skill acquisition.
4. Explore the potential role of technical feedback and instruction in relation to personalized goal setting in order to bring about changes in movement behaviour.
5. Explore the potential role of technical feedback based on personalized data to prevent injuries by testing on fatigue and critical movement errors.

Practical recommendations for trainers and coaches

1. Address inter-segmental timing in every exercise when teaching to throw fast.
2. Teach pitching according to the 10 biomechanical key points identified in the playbook.
3. Optimize players' focus of attention during performance by familiarizing players' attention focus to the movement effects.
4. Deploy technical devices, guided by instructions about the movement itself, to correct critical sub-movements that present a high risk on injuries.



Summary

Introduction

Pitchers play an important role in baseball games and have a considerable share in their outcomes. A pitcher's success is in large part determined by his ability to generate high ball velocities. Such an explosive throw places high demands on the pitcher's body, which together with the high work load results in high injury rates and in professional baseball, in a corresponding loss of invested player salaries. To gain a better understanding of the possibilities to improve the performance of pitchers and to decrease the risk of injury, quite a number of mechanical studies have been performed. These studies were focused predominantly on kinematic and kinetic variables and their relation with throwing velocity and the associated injury mechanisms. In this context the mechanical load on individual joints was examined, but the interaction between joints remained thus far underexposed. In contrast, the focus of the biomechanical research in the present thesis is on the coordination between limb segments and the potential role of intersegmental timing on the generation of high throwing velocities in elite pitchers. Detailed research on the kinematic chain in pitching can identify essential movement characteristics that contribute to a high throwing velocity and a low risk of injury. A crucial question in this regard pertains to the types of instruction and feedback that should be provided for this purpose. Numerous studies have shown that instructions that direct the learner's attention towards the effect of the movement in the environment (an external focus of attention) rather than towards the movement itself (an internal focus of attention) improve both motor performance and motor learning. This seems very relevant for pitching, in the context of which clear environmental goals can be identified on which the pitcher's attention may be focused. In the present thesis it is therefore investigated to what extent baseball coaches introduce an external focus of attention while instructing young talented pitchers, and whether the effectiveness of these instructions is indeed greater than instructions evoking an internal focus of attention.

Aim

The overarching aim of this thesis was to gain insight into the conditions that lead to fast and safe pitching and how young elite baseball trainers can be trained to this effect.

Results

In this thesis a number of variables were identified that are associated with fast and safe throwing. In **chapter 2**, the association between the timing of sequential rotation of body segments and throwing velocity was examined by measuring the rotation velocity using the marker set-up recommended by the International Society of Biomechanics (ISB). The study was conducted with a homogenous group of young elite pitchers; within this group of found the inter-

segmental timing between pelvis and thorax was found to be a predictor of throwing velocity. In **chapter 3** empirical evidence was found for an association between throwing velocity and knee extension of the lead leg after front foot contact as well as peak thorax rotation velocity. The findings in this chapter were in agreement with those of previous studies on the kinematics of the baseball pitch. **Chapter 4**, the last chapter of the first part of the thesis, provides insight into the development of the functionality of the shoulder. The level of upward scapular rotation was examined in young baseball players at different degrees of upper arm abduction. during upper arm abduction was studied in elite youth pitchers. It was found that in the static abduction positions than the scapula of the other arm. Insight into the asymmetry and the difference in functionality between the throwing arm and non-throwing arm might have implications for the prevention of injuries during training.

In the quest for optimal instruction and feedback methods three studies were performed. In the first of these (**chapter 5**), it was investigated which types of instruction are routinely provided by pitching coaches during training. Pitching coaches gave twice as many instructions evoking an internal focus of attention than instructions evoking an external focus of attention. In view of the scientific literature about the effects of both types of instruction and the fact that in the training environment of baseball multiple external goals are present, this seems a relevant finding. A possible explanation for his gap between scientific knowledge and sports practice came to the fore in the literature review presented in **chapter 6**. This review revealed that most scientific studies on sports covered a relatively short time span of training in a laboratory or another strongly controlled environment, and generally involved students or novices as participants, as a result of which generalization to the daily training practice of experts is hardly possible. For this reason an ecologically more valid randomized controlled trial was conducted to chart the effects of instructions evoking an external and instructions evoking an internal focus of attention. This study was performed with pitchers from the national youth teams of Belgium, Germany, Italy and the Netherlands during their regular training and with their own coaches. After a five-week long training period no consistent differences were found in the tested performances as a function of both types of instruction. This finding contradicts with what was found in most previous studies. A possible explanation for this discrepancy is that the pitchers had long received internal-focus-of-attention instructions from their coaches, and were therefore more familiar with this type of instructions. Another possible explanation is that the skill level of the pitchers was already very high, as a result of which a ceiling effect may have occurred. In the last chapter (**chapter 7**), a sensor sytem was developed that provides real-time feedback about the rotation velocities of pelvis and thorax and the timing between the moment of peak rotation of both segments. The feedback system was used in a two-day intervention study, which

revealed that internal-focus-of-attention instructions in combination with real-time feedback resulted in the greatest improvement (viz. faster rotations) in the movement characteristics of the pitchers. Although this improvement was only of short duration, feedback about the pitching movement seems to be useful in bringing about, and perhaps also acquiring, of a fast and safe throwing technique.

General conclusions and further recommendations

The overarching aim of this thesis was to gain insight into the conditions that lead to fast and safe pitching and how young elite baseball trainers can be trained to this effect. We conclude that the training of pitchers should be focused on improvement of the relative timing between the peak rotation velocity of the pelvis and the thorax because this relative timing is closely associated with the throwing velocity. Also the rotation velocity of the thorax and the extension of the knee after front foot contact were associated with throwing velocity. Therefore, pitching training may be focused on these aspects as well.

Although the baseball training environment provides ample opportunities for the coach to direct the attention of pitchers externally, these are hardly used by pitching coaches. However, in an ecologically valid randomized clinical trial no statistically significant difference was found in effectivity between instructions evoking an external focus of attention and instructions evoking an internal focus of attention. Further research is needed to gain more insight into the type of instructions that are most beneficial for elite pitchers; in this research it should be ensured beforehand that the participants are sufficiently familiar with the instructions provided. It was also concluded that internal-focus-of-attention instructions in combination with real-time technical feedback can provide an effective method to change the movement technique of players within a single session. Future research is needed to determine how long this effect is preserved after training and how retention might be improved.

The findings presented in this thesis underscore the need to further develop innovative real-time feedback for baseball pitching training. Feedback from sensors can provide both players and coaches with information about the execution of the pitching action and increase the effectivity of instructions of coaches about this execution.

Samenvatting

Introductie

Werpers spelen een belangrijke rol in honkbalwedstrijden en hebben een groot aandeel in het wedstrijdresultaat. Het succes van een werper wordt voor een belangrijk deel bepaald door diens vermogen om een bal met hoge snelheid te werpen. Zo'n worp gaat gepaard met een zware belasting van het lichaam, die tezamen met de hoge werkdruk van werpers resulteert in een hoog blessurepercentage en bij het professionele honkbal in een navenant verlies aan geïnvesteerde spelerssalarissen. Om een beter begrip te krijgen van de mogelijkheden om de prestaties van werpers te verbeteren en hun kans op blessures te verminderen zijn nogal wat biomechanische studies uitgevoerd. Deze waren voornamelijk gericht op de rol van kinematische en kinetische variabelen en hun relatie met de werpsnelheid, en een beter begrip van blessuremechanismen. Daarbij werd de mechanische belasting van verschillende individuele gewrichten bestudeerd, maar de wisselwerking daartussen bleef tot dusver onderbelicht. In dit proefschrift gaat de aandacht juist uit naar de coördinatie tussen deze lichaamssegmenten en de potentiële rol van inter-segmentale timing bij het genereren van hoge werpsnelheden bij tophonkballers.

Door het onderzoek naar de kinematisch keten bij het pitchen kunnen essentiële bewegingskenmerken worden geïdentificeerd die tot een hoge werpsnelheid en een laag blessurerisico leiden. Een belangrijke vraag in dat verband betreft de vormen van instructie en feedback die daartoe moeten worden verstrekt. Uit meerdere studies is gebleken dat instructies die de aandacht vestigen op het effect van de beweging in de omgeving (een externe focus van aandacht) in plaats van op de beweging zelf (een interne focus van aandacht) zowel de motorische prestaties als het motorische leerproces bevorderen. Dit lijkt zeer relevant voor het werpen omdat daar duidelijke omgevingsdoelen kunnen worden geïdentificeerd waarop de aandacht kan worden gericht. In het onderhavige proefschrift wordt dan ook nagegaan in welke mate honkbalcoaches bij hun instructies tijdens de training van getalenteerde jeugdthonkballers een externe focus van aandacht introduceren, en of de effectiviteit van dit type instructie inderdaad groter is dan op een interne focus van aandacht gerichte instructies.

Doel

Het overkoepelende doel van dit proefschrift is inzicht te krijgen in de condities die tot snel en veilig werpen leiden en hoe jonge tophonkballers daartoe getraind kunnen worden.

Resultaten

In dit proefschrift werd een aantal variabelen geïdentificeerd die gerelateerd zijn aan het veilig werpen met hoge snelheid. In **hoofdstuk 2** werd de associatie

tussen de timing van de opeenvolgende rotatie van bekken en romp bestudeerd door het meten van rotatiesnelheid volgens een door de International Society of Biomechanics (ISB) aanbevolen marker set-up. De studie werd uitgevoerd met een homogene groep van jonge tophonkballers; binnen deze groep bleek de de inter-segmentale timing tussen bekken en romp een voorspeller van de werpsnelheid. In **hoofdstuk 3** werd empirische evidentie gevonden voor de associatie van de werpsnelheid met het strekken van de knie na voetbodemcontact alsmede met de piekrotatiesnelheid van de romp. De bevindingen in dit hoofdstuk waren in overeenstemming met die van eerdere studies naar de kinematische aspecten van het werpen. **Hoofdstuk 4**, het laatste hoofdstuk in deel 1 van de dissertatie, geeft inzicht in de ontwikkeling van de functionaliteit van de schouder. De mate van opwaartse rotatie van het schouderblad werd bestudeerd bij jonge honkballers bij verschillende standen van abductie van de bovenarm. Hierbij bleek dat het schouderblad in statische posities van schouderabductie van de werparm meer opwaarts roteerde dan het schouderblad van de andere arm. Inzicht in de asymmetrie en het verschil in functionaliteit tussen werparm en niet-werparm kan van belang zijn bij het trainen om blessures te voorkomen.

In de zoektocht naar optimale instructie en feedbackmethodes werden drie studies uitgevoerd. In de eerste daarvan (**hoofdstuk 5**) werd onderzocht welke soorten instructies werpcoaches tijdens de training verstrekken. Het bleek dat de coaches twee keer zoveel instructies geven die leiden tot een interne focus van aandacht dan instructies die een externe focus van aandacht beogen. Gegeven de wetenschappelijke literatuur over de effecten van beide vormen van instructie en het feit dat in de trainingsomgeving van het honkbal meerdere externe doelen aanwezig zijn, lijkt dit een verrassende uitkomst. Een mogelijk verklaring voor deze kloof tussen wetenschappelijke kennis en de sportpraktijk kwam naar voren in de overzichtsstudie die in **hoofdstuk 6** werd gepresenteerd. Hieruit blijkt dat de meeste wetenschappelijke studies op het gebied van sport zich in een korte tijd in een laboratorium of een andere sterk gecontroleerde omgeving afspelen, waarbij de proefpersonen uit studenten of beginners bestaan, waardoor generalisatie naar de alledaagse praktijk met experts nauwelijks mogelijk is. Daarom werd een ecologisch meer valide randomized controlled trial uitgevoerd om de effecten van instructies gericht op een externe focus en een interne focus van aandacht in kaart te brengen. Deze studie werd uitgevoerd met werpers van de nationale jeugdteams van België, Duitsland, Italië en Nederland, tijdens hun reguliere training en met hun eigen coaches. Uit het onderzoek bleek dat er na een vijf weken lange trainingsperiode geen consistente verschillen waren in de geteste prestaties als gevolg van beide instructiemethodes. Deze uitkomst is in tegenspraak met wat in de meeste eerdere studies werd gevonden. Een mogelijke verklaring hiervoor is dat de werpers meestal al lang op een interne focus van aandacht

gerichte instructies van hun coaches hadden ontvangen, en er daardoor meer mee vertrouwd zijn. Een andere mogelijke verklaring is dat het niveau van de werpers al zeer hoog was, waardoor er van een plafondeffect sprake kan zijn geweest. In de laatste studie (**hoofdstuk 7**) werd een sensorsysteem ontwikkeld dat real-time feedback verschaft over de rotatiesnelheden van heup en romp rotatiesnelheden en de timing tussen het moment van piekrotatie van beide segmenten. Het feedbacksysteem werd gebruikt tijdens een tweedaagse interventie waaruit bleek dat instructies die gericht waren op de beweging zelf in combinatie met real-time feedback, de grootste verbetering (nl. sneller draaien) in de bewegingskarakteristieken van de werpers opleverde. Hoewel deze verbetering slechts van korte duur was, lijkt feedback over de werpbeweging behulpzaam te kunnen zijn bij het bewerkstelligen, en mogelijk ook het verwerven, van een snelle en veilige werptechniek.

Algemene conclusies en verdere aanbevelingen

Het overkoepelende doel van dit proefschrift was om inzicht te krijgen in de condities die tot snel en veilig werpen leiden en in hoe jonge tophonkballers daartoe getraind kunnen worden. We concluderen dat de training van werpers zich zou moeten richten op het verbeteren van de relatieve timing tussen de piekrotatiesnelheid van de heup en die van de romp, aangezien deze nauw samenhangt met de werpsnelheid. Tevens bleek dat de rotatiesnelheid van de romp en de streksnelheid van de knie na voetcontact met de ondergrond gerelateerd zijn aan de werpsnelheid. Ook op deze aspecten zou de training zich kunnen richten.

Hoewel de trainingsomgeving van het honkbal tal van mogelijkheden biedt voor de coach om de aandacht van werpers extern te richten, worden deze mogelijkheden nauwelijks benut door wercoaches. Uit een ecologisch valide randomized clinical trial bleek echter geen significant verschil in effectiviteit te bestaan tussen instructies gericht op een externe focus van aandacht en instructies gericht op een interne focus van aandacht. Aanvullend onderzoek is nodig om meer inzicht te krijgen in het type instructies waar tophonkballerspelers het meeste bij gebaat zijn, waarbij het van belang is ervoor te zorgen dat de proefpersonen vooraf voldoende bekend zijn met de aangeboden instructies. Geconcludeerd werd ook dat instructies die de aandacht intern richten in combinatie met real-time technische feedback een effectieve methode vormen om de bewegingstechniek van spelers binnen één sessie te veranderen. Uit toekomstig onderzoek zal echter moeten blijken in hoeverre dit effect behouden blijft na de training en hoe de retentie kan worden verbeterd.

De bevindingen in dit proefschrift illustreren het belang van de verdere ontwikkeling van innovatieve real-time feedbacksystemen in het honkbal. Feedback van sensoren kan zowel spelers als coaches informatie verschaffen over de bewegingsuitvoering en de effectiviteit van instructies van coaches daarover helpen verhogen.

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**Publication
Papers
Presentations**

Publications

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Meten aan de perfecte worp, *De Ingenieur*, Maart 2016.

Schouder en elleboogblessures in het honkbal, *Sport en geneeskunde*, Maart 2016.

Presentations

at international conferences

Thorax and pelvis rotation velocity in baseball pitching, ECSS 2014, Amsterdam, 07-2014.

The role of pelvis and thorax rotation velocity in baseball pitching, ISBS 2016, Tsukuba, Japan, 07-2016.

Internal and external focus in baseball pitching training, EBCA, Mulhouse, France, 11-2016.

Timing of thorax and pelvis rotation, IME, London, UK, 12-2016.

at scientific meetings

Thorax and pelvis rotation velocity in baseball pitching, Dag van Sportonderzoek, 10-2014.

Timing of thorax and pelvis rotation, SECSI 2016, Amsterdam 04-2016.

Internal and External focus in baseball pitching training, SECSI 2017, Delft, 04-2017.

Focus of attention and learning strategies. Presentation at Japan – Netherlands Workshop “Baseball-science meets Practice”, Dutch Embassy, Tokyo, 09-2017.

Poster: External vs internal focus of attention in day-to-day baseball pitching training - a multicenter, randomized controlled cross-over intervention involving four national youth teams, AMS-day, Amsterdam, 03-2018

Baseball lectures and workshops

Presentatie en overleg screening jeugd honkballers voor internationale coaches en Jeff Krushell, Hoofddorp, 07-2014.

Screening in youth baseball pitching, European Coach Congres, Rotterdam, 12-2014.

Instructies tijdens honkbal training. Presentatie voor academie coaches, Hoofddorp, 09-2015.

External and internal focus in training situations, MLB Elite Camp, Regensburg, Germany, 09-2015.

10 keypoints in baseball pitching, MLB Elite Camp, Barcelona, Spain, 03-2016.

Motor learning in baseball, TC 4 curses KNBSB, Hoofddorp, 02-2017.

Demo: feedback in baseball pitching, presentation at Japan – Netherlands Workshop “Baseball-science meets Practice”, Dutch Embassy, Tokyo, 09-2017.

Student projects

Department of Human Movement Sciences, Vrije Universiteit Amsterdam

Bachelor Research Projects (15 ECTS)

-Wouter Schallig en Bart van Trigt. (2014). *The effect of lower extremity kinematics on the throwing velocity of youth baseball pitchers.*

-Alyanne Evertse en Thom Veeger. (2014). *Shoulder range of motion is not associated with ball speed in youth baseball pitchers.*

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Master Research Internships (24 ECTS)

-Maurice Pasteuning. (2015). *Focus of attention in baseball pitching.*

Department of Biomechanical Engineering, Delft University of Technology

Bachelor Research Projects (15 ECTS)

-Lieve Bouwman, Dianne Hondeborg, Tobias Stinebosch and Daan Haak. (2016)
Baseball Pitching: Looking for the optimal footwork.

Master Research Internships (24 ECTS)

- Maryam Sharify. (2015). *Powerflow modelling during fastball pitching.*
- Tristan Li. (2016). *Scapular kinematic during baseball pitching.*
- Peter Hordijk. (2016). *Musculoskeletal modelling of baseball pitching.*
- Liset Vliegen. (2017). *Real-time feedback during baseball pitching*

The Hague University of Applied Sciences

-Matthieu Elfferich en Daphne van Amelsvoord. (2016). Feedback mechanismes.

Montaigne Lyceum, The Hague

-Profielwerkstuk voor door Milou Nederveen. "De belangrijkste spiergroepen voor het pitchen bij honkbal. Het verband tussen de werpsnelheid en de spieren van de heup- en schouderabductie.

ALL STAR





Erik van der Graaff studeerde in 2013 af voor zijn Master bewegingswetenschappen met als onderwerp de ideale techniek van de honkbal pitch. Hierna startte Erik zijn PhD project: 'project FASTBALL' (fast and safe throwing in baseball). Het overkoepelende doel van dit onderzoek was inzicht te krijgen in de condities die tot snel en veilig werpen leiden en hoe jonge tophonkballers daartoe getraind kunnen worden. In deze dissertatie wordt deze zoektocht beschreven. Na afronding van zijn project is Erik door NOC*NSF aangesteld als Embedded Scientist en startte het Baseball Science Centre. Via deze plek wordt onderzoek en innovatie in het honkbal ondersteunt. Als Embedded Scientist werkt Erik samen met het Nederlands honkbal- en softballteam aan het verwezenlijk van de Olympische droom op weg naar Tokyo 2020.

Erik van der Graaff finished his Master in Human Movement Sciences in 2013 on the topic of the optimal throwing technique in baseball pitching. After his study, Erik started the PhD project 'project FASTBALL' (fast and safe throwing in baseball). The overarching aim of this project was to gain insight into the conditions that lead to fast and safe pitching and how young elite baseball players can be trained to this effect. This doctoral thesis describes this search. After the PhD project Erik was employed by the National Olympic committee as an Embedded Scientist and founded the Baseball Science Centre. The Centre facilitates research and innovation in baseball. As an Embedded Scientist Erik works together with the Dutch baseball- and softballteam to realize the Olympic dream towards Tokyo 2020.