Implications for ACL injury prevention: The effect of visual feedback on joint loads and intrinsic motivation

I.N. Boone

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S2995859
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Department of Psychology
University of Groningen
Examiner/supervisor: Ruud J. R. den Hartigh
Supervisor of the organization: Anne Benjaminse

Abstract

Anterior cruciate ligament (ACL) injury prevention should remain a top priority, because of the high costs, social expenditures and the harmful effects on a person's talent development and quality of life. Because the risk of ACL injury decreases with lower knee loading, we aim to identify the effect of visual instruction and feedback interventions on joint loads. Moreover, we examined the effect of visual instruction and feedback on intrinsic motivation. Twenty-four young talented football players participated. They were divided into a control group, instruction group and instruction + visual feedback group. Every group participated in a 6-week program that consisted of a pretest, training weeks one to four (T1 - T4), a post-test and retention test. Lower-limb joint kinematics were collected through wearable reflective markers (Vicon) during sidestep cutting. Two digital cameras provided the option for visual feedback and in between the exercises, a composed intrinsic motivation inventory was filled out. The data was analysed with the use of repeated measures ANOVA. A main effect of time on joint loads was found: scores at the pretest were better than at the post-test and retention test . Furthermore, a main effect of time on intrinsic motivation was found: scores at T3 were significantly higher than at T1. This study provided insight into how intrinsic motivation and joint load scores change over time, regardless of intervention group. Future research should focus on making this research more transferable to the field to increase ecological validity.

Keywords: motor learning, knee loading, video feedback, self-determination theory, football

Implications for ACL injury prevention: The effect of visual feedback on joint loads and intrinsic motivation

Kara Lang was one of the biggest talents of the Canadian women's football team, debuting at the age of 15. A bright future ahead of her, but she was forced into retirement a few years later after she suffered two serious anterior cruciate ligament (ACL) injuries (Molinaro, 2014). In high-risk sports including football, basketball and volleyball, noncontact ACL injuries commonly occur. In the Netherlands alone, 4000 ACL injuries occur in football every year and approximately 70% of ACL injuries have a noncontact aetiology (Boden et al., 2000). Moreover, the majority of noncontact ACL injuries happen while the athlete is landing from a jump or quickly decelerating with a change of direction (Voskanian, 2013). Due to both modifiable (such as neuromuscular control, biomechanics) and nonmodifiable (such as anatomy, genetics) elements, female athletes are generally more likely to suffer an ACL injury than male athletes (Silvers-Granelli, 2021). After an ACL rupture, treatment options include an early ACL reconstruction and rehabilitation or rehabilitation and optional reconstruction in the event of prolonged instability. In terms of clinical outcomes, neither treatment differs in its ability to cause post-traumatic osteoarthritis (Eggerding et al., 2021). The expense of an ACL injury includes the financial cost of reconstructive surgery and rehabilitation as well as lost participation time (Pfeifer et al., 2018). In the Netherlands, the total cost from the health care system perspective alone is approximately 6367 euros for early reconstruction and rehabilitation and 4267 euros for rehabilitation and optional reconstruction (Eggerding et al., 2021). In addition, when compared to demographic norms and even more when compared to peers, patients' knee-related quality of life is affected for more than 20 years after ACL rupture (Eggerding et al., 2021). Because of the high costs, social expenditures and the harmful effects on a person's talent development and quality of life, ACL injury prevention is paramount.

In the current thesis, firstly, I shed light on the ACL injury mechanism, to get a better understanding on how the injury occurs. Secondly, with this knowledge, I discuss one of the most effective ways of preventing an ACL injury, which is teaching athletes to lower knee joint loads by providing them (visual) feedback on their performance. Lastly, I discuss the role of intrinsic motivation in this intervention, because this seems to be an important factor in motor learning. Hence, I aim to identify the effect of visual feedback on joint loads and on intrinsic motivation.

ACL injury mechanism

Injury prevention starts with understanding the mechanisms that cause injuries. Despite the fact that there are many methods available to improve our understanding of the mechanisms causing ACL injuries (such as cadaveric studies, laboratory investigations, and mathematical modelling studies), video analysis is a widely used tool to examine playing situations and biomechanics before and during injuries (Boden et al., 2010).

In a study by Lucarno et al., (2021), the mechanism and situational pattern of 35 injury videos of professional female football players were examined, while 29 cases allowed for biomechanical investigation. When picture quality permitted, kinematic analysis was done for the initial contact (IC) and the injury frame (IF) for both indirect and noncontact injuries. Videos needed to meet certain requirements in order to be used for biomechanical analysis, including a camera angle that approximated a sagittal or frontal perspective of the injured athlete and an unobstructed view of the athlete herself and the foot making contact with the ground. Considering that it was thought that ACL injuries typically occur 40 milliseconds or less after IC , the IF was visually determined (Della Villa et al., 2020). The results show that, in the sagittal plane at IC, players demonstrated a nearly upright trunk, an early flexed hip, an initial knee flexion, and a plantarflexed ankle, with a predominance of a flat foot and an abducted hip, as well as a abducted or neutral knee, were also seen. The findings confirm the importance of a ‘’knee-dominant’’ pattern in ACL injuries in the sagittal plane. The 30° knee angle is believed to be a susceptible position and one that results in increased ACL loading (Withrow et al., 2006). Motion was primarily restricted to knee flexion from the IC to the IF, with minimal modifications to ankle flexion and no changes at the hip/trunk level. Along with the knee dominant, sagittal plane technique, different frontal-and transverse- plane motions were also detected. As seen in previous research (Della Villa et al., 2020), they observed a strong lateral trunk tilt towards the injured limb, along with trunk rotation toward the intact leg and the new planned running direction. Collectively, these movements provide large external knee abduction moments, which worsen ACL strain.

In an additional effort to pinpoint the most typical kinematic positions connected to ACL injuries during competitive play, Boden et al. (2000) used retrospective video analysis. They described a lower extremity alignment when the foot was planted during deceleration, in which the tibia was externally rotated, the knee was almost fully extended, and the knee had collapsed valgus. The prevalent mechanism of knee abduction in female football players has also been mentioned in more recent research (Dix et al., 2021). Carlson et al. (2016) noted that the majority of the ACL injuries had fairly similar deceleration positions, but they also noted that the body's centre of mass was frequently behind and away from the base of support (area of foot to ground contact). There is therefore growing evidence that the most common noncontact injury mechanism in female athletes happens during a deceleration task with high knee internal extension torque combined with dynamic abduction rotation, with the bodyweight transferred to the injured leg and the plantar surface of the foot fixed flat on the ground (Carlson et al., 2016).

Furthermore, during a vertical drop jump test, Leppänen et al. (2016) assessed the peak vertical ground reaction force (vGRF), peak knee abduction moment and knee flexion angle at IC. Data on 171 female basketball and floorball players (ages 12 to 21) were gathered. The participants were then monitored for new ACL injuries for one to two years after the screening test began. Fifteen additional ACL injuries developed during the research period. The findings demonstrated that adolescent female basketball and floorball players who experienced stiff landings with less knee flexion and more vGRF had an elevated risk of ACL injury (Leppänen et al., 2016), which is in line with the previously discussed studies.

To summarize, the literature suggests that frontal plane knee loading during landing and cutting tasks should be reduced, knee valgus collapse should be reduced and vGRF should be reduced in the sagittal plane by landing more ‘’softly’’ . To accomplish this, a promising intervention is providing the athlete with feedback on their performance, which will be discussed next.

Feedback

In general, feedback is information provided to someone in an effort to change an activity (Winstein, 1991). To prevent ACL injury, prevention programs should teach athletes to apply a high knee range of motion (ROM) in the sagittal plane and low knee ROM in the frontal plane during landing to lower knee joint loads (di Paolo et al., 2022a). Several studies have shown that providing the athlete with feedback before, during or after various exercises where lowering joint loads may prevent ACL injury (i.e. cutting manoeuvres, landing from a jump, quickly decelerating), is an effective method to realize this (Ericksen et al., 2015).

While feedback is crucial in any learning process, the most common understanding of feedback in the motor learning literature is that it informs the learner about his or her performance in relation to the task goal (Wulf & Lewthwaite, 2016). Observational learning, like video feedback, is a powerful tool for improving motor skill acquisition (Benjaminse et al., 2015). Imitation (copying bodily motions) is key, as it can activate mirror neurons, which can automatically translate observed movement to a motor program (Benjaminse et al., 2015).

Practitioners frequently provide instructions or feedback during practice that are directed to body movements (for example, ‘’lower your hips until your thighs are parallel to the floor’’) (Singh et al., 2021). This kind of attentional focus is known as internal focus in the context of motor learning. On the other hand, when an athletes’ attention is focused on the result of the movement (for example, ‘’imagine sitting down on a chair while landing’’), an external focus of attention is induced (Wulf, 2013). Dyad training and (real-time) visual or sensory feedback can also be used to improve motor performance and learning, as can a simple modification in the wording of instructions or feedback.

Research on motor learning over the previous 15 years has shown the advantages of instructions that create an external focus of attention (Wulf, 2013). According to the “constrained action hypothesis’’, an external focus of attention shortens the initial phases of learning and speeds up the learning process by stimulating automatic movement (Wulf et al., 2010). A focus on the movement effect, more precisely, encourages the use of unconscious or automatic processes, whereas an internal focus on one’s own movement produces a more conscious sort of control that restrains the motor system and interrupts automatic control processes (Wulf et al., 2010). Second, the development of effective and efficient movement patterns is improved by an external focus of attention. The premotor cortex is active even when no movements are produced, according to neuroimaging studies (Zachry et al., 2005). The premotor cortex is well known for its function in the planning, execution and conscious recall of remembered actions. Thus, focusing on memorized movements may drain mental resources from movement control. This indicates that more resources are available to pay attention to other game elements when a skill is mastered with an external focus of attention. With an external focus of attention, learning new motor abilities can be retained longer (Benjaminse et al., 2015).

The effectiveness of feedback and training techniques can further be improved by giving the athlete a visual example (dyad), such as a peer athlete carrying out the task with the appropriate movement patterns (McNevin et al., 2000). This way, learning can occur by observing the behaviour of others, called vicarious learning. Such social learning is efficient without requiring the observer to receive direct feedback (Mayes, 2015). For instance, balance on a stabilometer was assessed in healthy university students by having them maintain the platform’s horizontal position throughout each 90-second trial. The findings showed that alternating between practice types with a partner (dyad) was more successful in retention and transfer assessments than individual practice (Shea et al., 1999). Furthermore, due to social interaction and rivalry, practice in pairs might provide additional learning benefits and boost motivation (Granados & Wulf, 2007). This can also be explained by the need for relatedness, which involves understanding, feelings of respect, and connectedness which results from interpersonal relationships (Deci & Ryan, 2000). Athletes may be inspired to set objectives that are more challenging when they practice in an interactive style with a partner because they will be “competing’’ with a peer. For instance, when performing a single leg squat, one athlete may unconsciously try to mimic the other’s deep knee flexion. The athlete’s sense of accountability for participation in the learning and treatment process might be increased by exercising with a partner and discussing learning ideas (Benjaminse et al., 2015).

Athletes might use video feedback to focus on their own needs or the requirements of a team of athletes. As an illustration of an “expert video’’, a video of one teammate performing well in a drop jump after catching a basketball might be shown to all the team’s guards. In this case, the athlete who is the “expert’’ would see his own video as the target performance and the other athletes would see a video of a model (their teammate) as the target performance. Video feedback seems to be a simple and useful technique that may be used in nearly any clinical context to enhance lower extremity dynamics during jump-landing activities (Benjaminse et al., 2015). In addition, Onate et al. (2001) used both visual and verbal feedback in an effort to lessen landing forces and improve movement patterns. This was put to the test during a jump-landing exercise in which participants had to jump as high as they could while using their dominant hand to touch a Vertec vertical jump trainer while standing directly behind a force plate. In comparison to the internal feedback group and control group, the group that got both verbal and self-video feedback dramatically decreased peak vGRF.

Additionally, Dempsey et al., (2009) recruited experienced team sport athletes (football, Australian football and rugby) for whole body sidestep cutting technique modification. Before and after undergoing six weeks of technique modification training, participants were evaluated while ground-reaction force and motion data were being gathered. Participants received vocal and visual feedback during training, which was conducted by a single teacher for the specific technique goal. Footage of their own performance was included in the visual feedback to give them immediate feedback on their sidestep cut technique, along with reference video of athletes executing the desired technique. Participants attempted to maintain an upright torso with the torso facing in the direction of movement, bring the stance foot gradually closer to the midline of the body and guarantee the stance foot was neither turned in nor turned out. The 3-dimensional knee loading during sidestep cutting was calculated using a kinematic and inverse dynamics model. The findings demonstrate that the participants' sidestep cutting technique, particularly in terms of foot placement distance from the pelvis and torso lateral flexion, significantly changed at initial foot-ground contact. The peak knee abduction loading of the knee during the weight acceptance phase of the sidestep cut was also 36% lower as a result of these technique improvements, which might reduce the risk of an ACL injury.

To summarize, providing athletes with feedback on their performance, seems to be an effective method in teaching the correct movement patterns to lower ACL injury. Showing an "expert'' video, giving athletes another form of visual feedback or vocal feedback, where the focal point lays on external focus on attention seems to be important. Furthermore, practicing in pairs might provide additional learning benefits and boost motivation. In addition to the learning benefits, it is likely that such effective feedback methods also have beneficial psychological effects. Indeed, self-modelling, an external focus, and practicing with another individual may positively influence motivation, which will be discussed next.

Motivation

The term ''motivation'' can be used broadly and inclusively to refer to a variety of characteristics that affect behaviour's direction, energization and intensity (Hagger et al., 2014). Wulf & Lewthwaite (2016) propose the optimizing performance through intrinsic motivation and attention for learning (OPTIMAL) theory, which is based on the idea that motivational (such as social-cognitive and affective) and attentional influences on behaviour are essential to understanding motor learning. They claim that while these factors may be accentuated or diminished within individuals, they are comparable across human learners and affect motor skill performance and learning. The fact that some motivational elements, particularly those that support intrinsic motivation or fulfil basic psychological needs, have been proven to influence performance and learning in areas other than movement, is probably not a coincidence (Hagger et al., 2015).

Intrinsic motivation is seen as the most common type of autonomous motivation, reflecting the reasons people act in a certain way for the enjoyment and interest they gain from doing so (Hagger et al., 2014). Autonomous motivation is defined as engaging in an activity because it is thought to be congruent with intrinsic objectives or results and emerges from the self (Hagger et al., 2014). To put it another way, the behaviour is self-determined. According to the self-determination theory (SDT), there are three basic psychological needs: competence, autonomy and relatedness that play an important role for the motivation of people (Sanli et al., 2013). A self-controlled practice environment can support the learner's psychological needs by fostering feelings of competence and autonomy, which can result in long-lasting behavioural changes (Sanli et al., 2013). Providing the athlete some control over a practice session (i.e., an active part in determining when to get feedback) for instance, may improve motor skill learning. It encourages the athlete to take a more active role in practice, boosting motivation and increasing the amount of effort put in (Benjaminse et al., 2015). Moreover, having some control over one's abilities can boost self-efficacy and exercises become more intrinsically motivating when they are sport-specific and relatively challenging (Benjaminse & Verhagen, 2021). Furthermore, according to the SDT, the need for relatedness is also important in motivating people. This involves understanding, feelings of respect and especially connectedness which results from interpersonal relationships (Deci & Ryan, 2000). That is why practice in pairs might provide additional learning benefits, due to social interaction and (healthy) rivalry, which can boost motivation (Granados & Wulf, 2007). Moving along the continuum from external and controlling motives to ones that are more autonomous, according to the SDT, results in the process of internalizing motivations (Sanli et al., 2013).

Moreover, in the motor learning literature, the influence of feedback on the performer's motivational state is very interesting. Recent studies have shown that giving feedback after adequate trials as opposed to bad ones led to more efficient learning (Wulf & Lewthwaite, 2016). Participants who received positive normative feedback showed increased motivation and displayed increased automaticity and efficiency in motor control than those who received negative or no normative input. Positive normative feedback also produced qualitative differences in movement control (Wulf & Lewthwaite, 2016). In addition, a few studies contrasted the outcomes of edited video feedback regarding students' best performance (referred to as ''self-modelling'') with video input about their actual performance, no video feedback, or spoken instructions (Wulf & Lewthwaite, 2016). It is interesting to note that learners who saw the edited videos of their finest trampoline or swimming technique, outperformed other groups in terms of learning. Furthermore, self-modelling increased intrinsic motivation and performance satisfaction (Clark & Ste-Marie, 2007).

It is clear that (intrinsic) motivation plays a role in motor learning. Research has shown that athletes improve their performance in certain situations when intrinsic motivation is higher. Also, positive feedback seems to influence the motivational state in a positive way. What the exact role of intrinsic motivation is in this feedback process is still unclear. So more research needs to be done on the relationship between feedback and motivation in specific contexts.

The current study

Taken together, previous research suggests that feedback and intrinsic motivation both play a role in motor learning. However, research that takes both into account within one design is lacking. In the current research, we aim to identify the effect of visual instruction and feedback on joint loads and on intrinsic motivation. It is hypothesized that receiving instruction and visual feedback is more successful in lowering knee joint loads compared to receiving instruction only, or no instruction or visual feedback at all. This is in line with research by Benjaminse et al., (2015), who stated that observational learning, like video feedback, is a powerful tool for improving motor skill acquisition**.** Furthermore, Hagger et al., (2015) stated that motivational elements, especially those that support intrinsic motivation or fulfil basic psychological needs, have shown to affect motor skill performance and learning. In line with Hagger et al., (2015), the second hypothesis is that receiving instruction and visual feedback will have a positive effect on intrinsic motivation compared to receiving instruction only, or no instruction and visual feedback at all.

Methods

Participants

Participants in this study were recruited from the Regional Talent Centre (RTC) in Groningen, the Netherlands. The RTC offers talented individuals a place in one of the top sport talent schools (Groningen, Heerenveen and Emmen). These schools have an adapted timetable, classes start later in the morning and finish earlier in the afternoon. In addition, athletes may take time off for prestigious tournaments. This way, the students have enough time to combine their sport with school. A total of 24 young talented female football players participated in this study. The average age was 14.71 years (*SD* = 2.33), mean height was 167.35 centimetres (*SD* = 5.66) and mean mass was 55.02 kilograms (*SD* = 7.78).

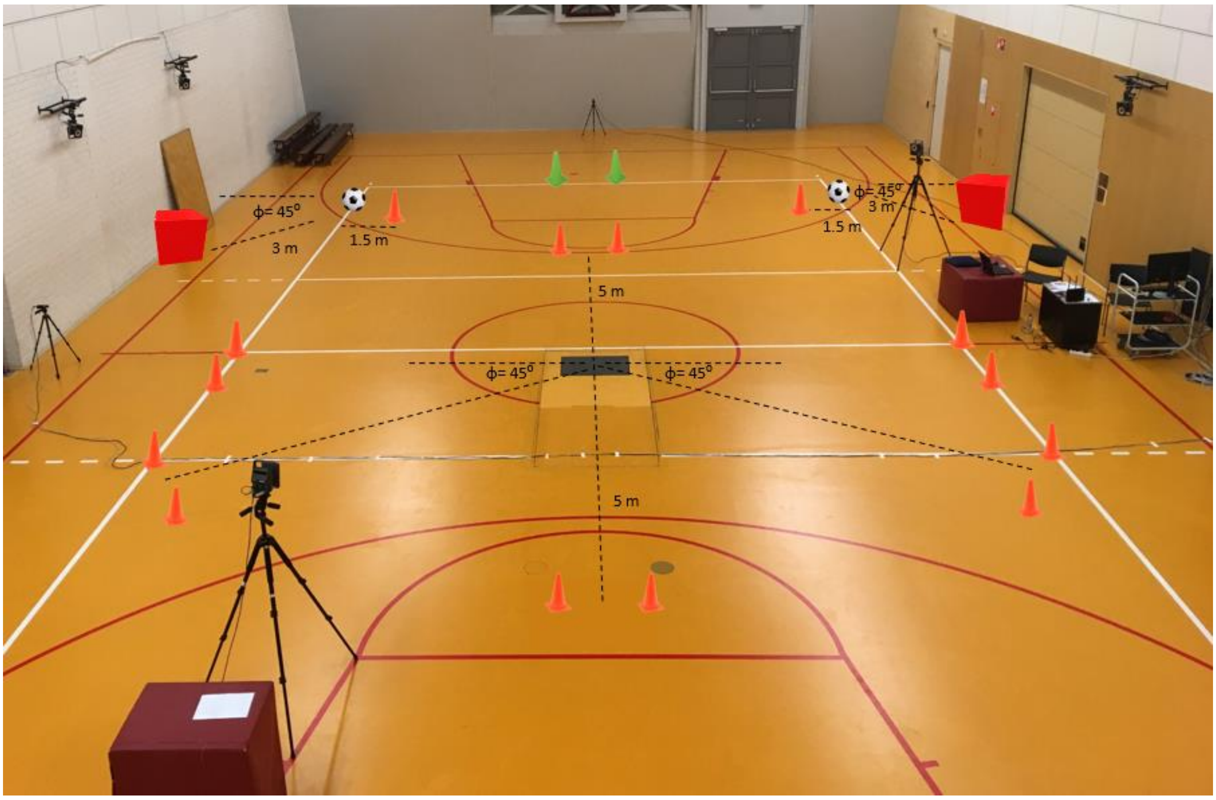
Material/procedure

The present study was approved by the ethics committee of the University Medical Centre Groningen, the Netherlands (ID number: METc 2018.249). Before participating in this research, the participant and at least one of their parents or legal guardians signed written informed consent. Of the 24 participants, seven were assigned to the control group, nine to the “instruction’’ group and eight to the “instruction + visual feedback’’ group.

In a period of approximately six weeks, participants had to be present in the lab five times (figure 1). L0 baseline to L5 immediate post-test was done within four weeks and the L6 retention test was done one to two weeks after L5. The participants had to do three exercises every time (single-leg hop, sidestep cutting, and double-leg hop), which differ slightly in the way they had to be executed each week. In this study, only the sidestep cutting exercise was analysed. With the sidestep cutting exercise, the participants utilized a 5 meter approach run, followed by a 1-foot landing with the dominant leg on the force plate and a change of direction of approximately 45^{o} and then run through a gate 5 meters away (week 1). The exercise became more difficult and more sport-specific every week. For example, in figure 2 the sidestep cutting exercise of training week three (T3) is shown. This is more sport specific, because the participants had to kick a ball against a box before they executed the 5 meter approach run. Furthermore, a ‘’buddy’’ was used to guide the participants through the course. This ‘’buddy’’ started the exercise and the participant followed shortly after. The buddy also decided through which gate the participant had to go, so in which direction the sidestep cut was executed. Only at T4 the buddy was not used, here all the cones representing gates were replaced with speed light gates which lit up when the participant ran through the first gate. Only the sidestep cut through the side of the non-dominant leg was recorded. All the sidestep cutting exercises of every week can be found in appendix A. At baseline, each participant had to complete five successful trials of the sidestep cut. After the baseline test, training weeks one to four were executed, where now 10 successful trials were needed. The immediate post and retention tests finalize the participation of the athlete. Five successful trials were needed here as well.

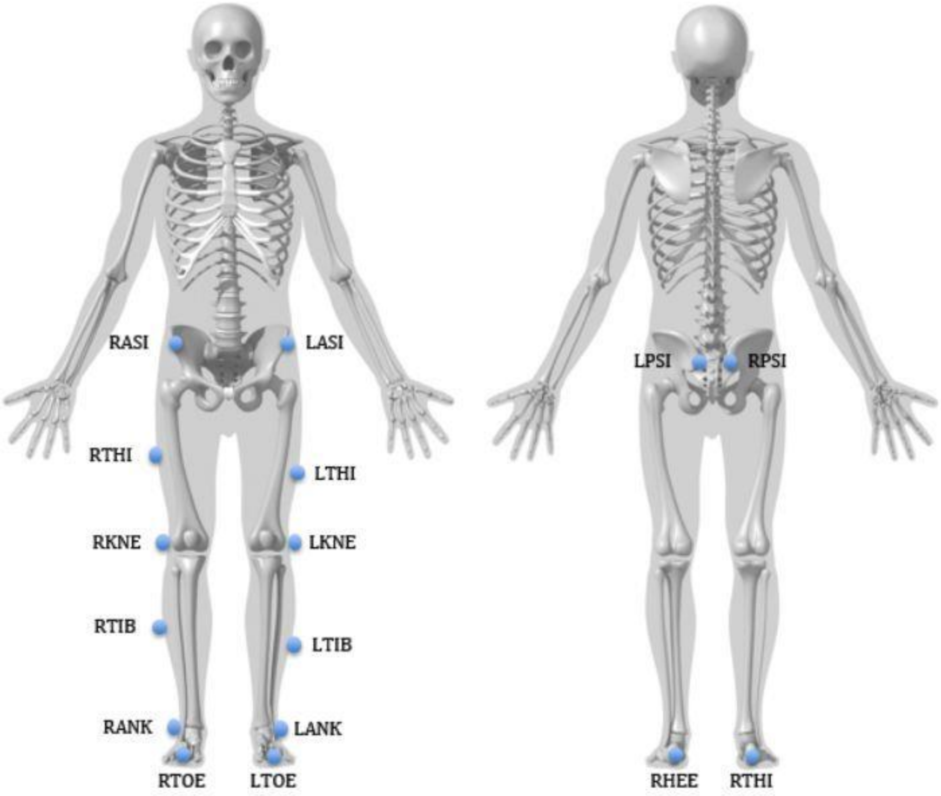
Figure 1. *Design of current study*

Figure 2. *Setup of sidestep cutting exercise week 3*



Prior to the test, each participant’s body height and mass, leg length, knee and ankle width were measured. Furthermore, 16 reflective markers were applied to the lower extremities over anatomical landmarks as per the plug-in gait marker set (Nexus | Software for Motion Capture in Life Sciences, 2022): on the shoe over the second metatarsal head and over the posterior calcaneus, lateral malleolus, lateral shank, lateral knee, lateral thigh, posterior superior iliac spine and anterior superior iliac spine (figure 3). Furthermore, five more reflective markers were placed on the upper body: seventh cervical vertebra (C7), tenth thoracic vertebra (T10), right scapula, processus xiphoideus and manubrium.

Figure 3. *Plug-in-gait marker placements lower extremity*



In order to record marker position and ground-reaction force data simultaneously, eight high-speed cameras and two force platforms were used. Before beginning the exercise, a static calibration trial was done to establish the anatomic segment coordinate systems. Vicon Nexus v2.14 software (Nexus | Software for Motion Capture in Life Sciences, 2022) was used to determine marker trajectories. From the flexion at first contact with the ground through the highest flexion during the landing phase, the knee and ankle flexion range of motion were determined. With the use of a matlab script, the knee joint loads were calculated. After running the script for a trial, a graph with three lines and a grey area would show, with time on the x-axis and force on the y-axis. To get the joint loads score, the black dotted line needed to be in the correct position. This could be done with the ‘’auto’’ function, or with the “do it yourself” option, where the cursor could be moved to the correct position. The correct position was carefully decided by an expert and had to be consistently in the same place within the five trials. The mean score of the five trials for baseline, immediate post and retention test were calculated and used for analysis.

Moreover, two digital cameras were placed in the lab, with a frontal and sagittal view. This way, the participant could get visual feedback on her performance in between trials. A video of an “expert’’ performing the exercise was shown to the participant prior to trial one.

The task goal was to try to mimic the performance of the expert' as well as possible. In training weeks one to four (T1 - T4), after the fifth successful trial, the participant was given another chance to view the expert video. Furthermore, the participants of the visual feedback group could ask to see their own performance after a successful trial at any time. This way they could see where they could improve compared to the expert'. The control group did not get any form of feedback.

In between the exercises the participant had to fill out a questionnaire, including a composed intrinsic motivation inventory (cIMI), which can be found in appendix B. The cIMI includes the subscales competence, pressure, enjoyment, effort and autonomy. These subscales were measured on a 7 point Likert scale. The answer possibilities ranged from 1 (''not true at all'') to 7 (''completely true''). The content of the questionnaire was established in cooperation with a specialist focused on injury prevention. The questionnaire is composed of the intrinsic motivation inventory (IMI) of the centre for self-determination theory (Intrinsic Motivation Inventory (IMI) – selfdeterminationtheory.org, n.d.) and the IMI of McAuley et al. (1989). An example of a question is: ''I enjoyed exercise 3 (sidestep cutting)". This was used to see if the motivation of the participants varied between the groups. The questionnaire was only filled out at T1 - T4.

Statistical analysis

The results were analysed using repeated measures ANOVA, with joint loads as dependent variable, time (3: pre, post, retention) as within-subject factor and group (3: control, instruction, instruction + feedback) as in between subjects factor. The influence of feedback on intrinsic motivation was also analysed using repeated measures ANOVA, with intrinsic motivation as dependent variable, time (4: T1 – T4) as within-subject factor and group (3: control, instruction, instruction + feedback) as in between subjects factor. A further exploration into the effect of the cIMI subscales was also analysed using repeated measures ANOVA, with a cIMI subscale as dependent variable, time (4: T1 - T4) as within-subject factor and group (3 :control, instruction, instruction + feedback) as in between subjects factor.

Results

Joint loads

Mean scores and standard deviations of the joint loads on the pretest, post-test and retention test for the control group, instruction group and instruction + feedback group are presented in table 1. The main effect of time on joint loads is statistically significant, sphericity assumed F(2, 21) = 3.30, $p = .047$, $\eta^2 = .14$. Scores at the pretest ($M = .54$, $SD = .040$) were better than at the post-test ($M = .68$, $SD = .071$, $p = .23$) and retention test ($M = .71$, $SD = .063$, $p = .063$). The repeated measure ANOVA revealed that the main effect of the treatment group on the average joint loads score across time is not statistically significant, F(2,21) = 1.02, $p = .38$, $\eta^2 = .089$.

Table 1. *Means and standard deviations of the joint loads (normalized for mass)*

	Pretest **M(SD)**	**Post-test** **M(SD)**	**Retention test** **M(SD)**
Control	.51(.20)	.67(.30)	.74(.21)
Instruction	.67(.22)	.68(.33)	.79(.30)
Instruction + feedback	.44(.16)	.68(.40)	.57(.38)

Intrinsic motivation

Mean scores and standard deviations of the overall score and the subscales of the composed intrinsic motivation inventory (cIMI) for the control group, instruction group and instruction + feedback group are presented in table 2.

The main effect of time on overall intrinsic motivation score is statistically significant, sphericity assumed F(3, 63) = 4.07, $p = .010$, $\eta^2 = .16$. Scores at T3 ($M = 6.11$, $SD = .13$) were significantly higher than at T1 ($M = 5.87$, $SD = .14$, $p = .039$). The repeated measures ANOVA revealed that the main effect of the treatment group on the average intrinsic motivation score across time is not statistically significant, F(2, 21) = .74, $p = .12$, $\eta^2 = .19$.

As an additional exploration, the repeated measure ANOVA of the cIMI subscales revealed that there was a statistically significant difference between the instruction group and the control and instruction + feedback groups on the subscale effort (F = 12.65, $p <.001$, $\eta^2 =$

.48). With the instruction group having a lower score on effort than the control and instruction + feedback groups. The other cIMI subscales showed no statistically significant difference between the groups.

Table 2. *Mean scores and standard deviations of the cIMI subscales*

		T1 **M(SD)**	**T2** **M(SD)**	**T3** **M(SD)**	**T4** **M(SD)**
Overall	*Control*	6.01(1.03)	6.06(.93)	6.22(.80)	6.05(.79)
	Instruction	5.36(.52)	5.58(.75)	5.94(.58)	5.72(.66)
	Instruction + feedback	6.23(.36)	6.34(.37)	6.17(.42)	6.44(.35)
Competence	*Control*	5.29(1.70)	5.71(.49)	5.71(.76)	5.29(.76)
	Instruction	4.11(1.05)	4.80(1.20)	5.56(1.01)	4.90(1.05)
	Instruction + feedback	5.38(.79)	5.69(.59)	5.50(.53)	6.00(.76)
Pressure	*Control*	5.43(2.30)	5.71(2.14)	6.00(1.91)	5.71(2.14)
	Instruction	6.11(1.05)	5.67(2.40)	6.11(1.76)	6.44(1.33)
	Instruction + feedback	6.75(.71)	6.88(.35)	6.69(.46)	7.00(.00)
Enjoyment	*Control*	6.38(.83)	6.28(.83)	6.33(.75)	6.33(.84)
	Instruction	5.89(.78)	5.89(.85)	6.26(.86)	5.56(.85)
	Instruction + feedback	6.23(.43)	6.12(.63)	5.87(.75)	6.12(.79)
Effort	*Control*	6.86(.38)	6.71(.49)	6.86(.38)	6.86(.38)
	Instruction	5.44(1.24)	6.22(.44)	6.00(.71)	6.00(.71)
	Instruction + feedback	6.69(.46)	6.75(.46)	6.63(.52)	6.63(.52)

Autonomy	*Control*	6.14(1.21)	5.86(1.21)	6.21(.91)	-
	Instruction	5.22(1.20)	5.33(1.32)	5.78(1.09)	-
	Instruction + feedback	6.13(.64)	6.25(1.04)	6.19(1.00)	-

Note. No scores at T4 for autonomy, because this question is about the order of the exercises and this could not be chosen anymore at T4 (because there was only one option left)

Discussion

The aim of this study was to identify the effect of visual instruction and feedback on joint loads and on intrinsic motivation. The results showed that there is no statistically significant difference between the groups on joint loads. However, a significant difference was found on the factor time, where the joint load scores at the pretest were lower than at the post-test and retention test, indicating that joint load scores were better at the pretest. The biggest difference was found between the pretest and the retention test. Furthermore, the results showed that there was a significant difference for intrinsic motivation on the factor time, where intrinsic motivation scores at T3 were significantly higher than at T1. Moreover, there is a statistically significant difference between the groups on the cIMI subscale “effort’’. Below I will further discuss these results in light of existing literature.

Effect on joint loads

It was hypothesized that receiving instruction and visual feedback is more successful in lowering knee joint loads compared to receiving instruction only, or no instruction or visual feedback at all, because providing participants with some sort of feedback has shown to be an effective method to modify movement technique (Benjaminse et al., 2015).

These hypotheses could not be supported, which is in contrast with the studies by Mayes (2015), McNevin et al., (2000) and Onate et al., (2001). It has been shown that teaching motor abilities through vicarious learning is a successful strategy (Mayes, 2015). A video of an expert carrying out the task with the correct movement patterns for instance, but even the observation of any other performer can have a beneficial effect on learning (McNevin et al., 2000). Every group trained with a “buddy’’ performing the task as well. The buddy was used to guide the participants through the course, so also performed the sidestep cut. Even though the participants got specific verbal instructions to not pay attention to how the buddy performed the sidestep cut, they might still have unconsciously changed their way of performing the exercise through vicarious learning. This could be a possible explanation for the non-significant difference between the control group and instruction group. Even though the instruction group had the extra video of an “expert’’ performing the task, the difference was too small.

Moreover, observing oneself can be an effective way to enhance motor skills according to Onate et al. (2001). During a jump-landing exercise, the self-video feedback group was more successful in decreasing peak vGRF compared to the control group and internal feedback group. A possible explanation for the non-significant difference between the groups in our study could be that the self-video feedback did not add enough to make an impact. The participants had the possibility to see themselves perform the sidestep cut after the trial, but they had to ask this and only had five opportunities to do this. Some participants were a bit shy or had to be reminded that this option was available. Because of this, some participants only saw themselves perform the task once, so it might not have added much. That might be the reason that the results do not match the hypothesis.

Interestingly, a significant difference was found on the factor time, where the scores at the pretest were lower than at the post-test and the retention test, indicating that joint load scores were better at the pretest. A more logical outcome would have been that the scores would improve after T1 - T4, so the scores would be better at the post-test and at the retention test, where perhaps a slight decrease would be visible at the retention test. A possible explanation for this result could be that participants put more effort into the first session (pretest) and levels of motivation were higher compared to the last sessions (post-test and retention test). This can have a theoretical and practical reason. Theoretically, Darby et al. (2013) showed that over the course of a semester an overall decline in students' motivation is seen. While male motivation peaked mid-semester, female motivation peaked at the beginning of the semester and gradually decreased (Zusho et al., 2010). Practically, with training weeks one to four the exercise became more and more sport specific, but with the post-test and retention test it is back to the basics (appendix A). The amount of effort and intrinsic motivation could be affected by this, hence why the scores at the post-test and retention test are worse.

Effect on intrinsic motivation

It was also hypothesized that receiving instruction and visual feedback will have a positive effect on intrinsic motivation compared to receiving instruction only, or no instruction and visual feedback at all. Motivational elements, especially those that support intrinsic motivation or fulfil basic psychological needs, have shown to affect motor skill performance and learning (Hagger et al., 2015). The instruction + visual feedback group got the most tools to improve their performance and they could decide when they wanted self-video feedback. A self-controlled practice environment can support the participants' psychological requirements by fostering emotions of competence and autonomy (Sanli et al., 2013). By giving the participant some control over the practice session, it encourages them to take a more active role, boosting motivation and increasing the amount of effort put in (Benjaminse et al., 2015).

The results show that overall intrinsic motivation increased over time, where scores at T3 were significantly higher than at T1. A gradually increasing intrinsic motivation score was seen between T1 and T3, where scores at T4 were lower again. This could be explained by the exercise becoming more sport-specific and therefore more meaningful, which increases motivation (Benjaminse & Verhagen, 2021). Scores at T4 being lower than T3 could be explained by the fact that at T4 the exercise stays the same, but no buddy is used and as mentioned before, practicing in pairs boosts motivation (Granados & Wulf, 2007). Also, female motivation peaks at the beginning of the semester and gradually decreases (Zusho et al., 2010), so T4 could be the turning point where the ''beginning'' of the semester/intervention is over and motivation slowly decreases (Zusho et al., 2010). Lastly, at T4 there is less autonomy, because the order of the exercises cannot be chosen anymore (because there is only one option left). Furthermore, on the cIMI subscale effort a significant difference was found, where the instruction group scored lower compared to the other two groups. This is not in line with the hypothesis and with previous research, because the amount of effort put in increases when the participant has a more active role in practice (Benjaminse et al., 2015). The lower effort scores in the instruction group compared to the instruction + feedback group does match the hypothesis, but the higher effort scores of the control group compared to the instruction group does not match the hypothesis. The small sample size could play a role in these results. It could be a coincidence that the majority of the instruction group put in less effort compared to most other participants in the other groups. On the other cIMI subscales, no significant difference was found.

A final interesting observation is that the tendencies of the joint loads and intrinsic motivation were not congruent. The best joint load scores were found at the pretest, whereas intrinsic motivation gradually increased from T1 and decreased after T3. Although there is no data on intrinsic motivation for the pretest, post-test and retention test, it would be more logical when intrinsic motivation would peak at T1, because this is the closest to the pretest (where the best joint load scores were seen). Or the post-test joint load scores should be the best, because this is the closest to T3/T4 where intrinsic motivation was the highest. Furthermore, according to the cIMI subscale effort, there was no decrease seen over T1 - T4, so this does not play a role. But again, there is no data on effort for the pretest, post-test and retention test. The reason why the best scores for the joint loads and intrinsic motivation are seen at these time points, both have their own explanation as mentioned before, but they are not congruent. It would be interesting to measure intrinsic motivation at the pretest, post-test and retention test as well to get more insight.

Limitations

First of all, an important limitation is that the analysis was done on a group level and not on an individual level. With an analysis on a group level, the data is aggregated, which means it is acquired by combining individual data. Data aggregation overlooks individual variation as if it were just a sort of statistical noise or measurement mistake, which results in information loss (Holderness, 2016). It is highly dubious whether results at the group level translate to individual processes. Findings at the group level may conceal significant subject variability and only permit ‘’on average’’ claims (Hill et al., 2021). In a study by Neumann et al. (2022), the aim was to investigate to what degree group-level statistics can be generalized to individual athletes, which is referred to as the ‘’ergodicity issue’’. They discovered statistical differences across their total data set and a symmetrical subset, which were evident in the findings of group- and individual-level analysis and therefore concluded that group-level statistics cannot be applied to individual athletes. As a result, when based on group-level results, recommendations for training programs of individual athletes may be suboptimal (Neumann et al., 2022).

Moreover, a power analysis was conducted using G*Power version 3.1.9.7 to determine the minimum sample size required to test the study hypothesis. Results indicated that the sample size needed to achieve 80% power with an effect size of .25, at a significance criterion of $\alpha = .05$, was $n = 36$ for repeated measures ANOVA (within-between factors). Thus, the obtained sample of 24 young talented female football players can be considered as a small sample. The inability to generalize the findings due to the small sample size is a disadvantage (Hackshaw, 2008). The reason for this small sample size is that it takes a lot of time to measure one participant. However, multiple trials (5) were done at every time point (so 15 in total), which increases the reliability and validity and therefore the statistical power (James et al., 2007). In addition, Hackshaw (2008) noted that it is frequently preferable to test the study on a smaller sample before enlarging it. So a benefit was that the small sample allowed for the exploration to be completed in the relatively brief amount of time that was agreed upon for the execution of the study.

Another potential limitation of this study, is a deficiency in the transfer of optimal movement strategies during training classes to automatic movements necessary for athletic and unanticipated field events (Benjaminse et al., 2015). In this research, participants are told to follow a predetermined trajectory at a specific pace and make a cut in a designated area. In order to maintain the protocol's standardization and repeatability, game-like variables are typically excluded, such as interactions between participants who are simultaneously handling the ball. The use of on-field data in the ACL injury risk screening is becoming more and more encouraged due to the absence of ecological validity in the laboratory setting (di Paolo et al., 2022b). The ecological validity investigates the generalizability of research findings to real-life settings. Although preventative strategies have been influenced by laboratory-based biomechanics, the identification of situational patterns on the field and the multifactorial nature of ACL ruptures have guided the constant updating of training methodologies, particularly in football academies. Therefore, it is essential to use an ecological method to add knowledge to these strategies, confirming the accuracy of the existing knowledge and incorporating context-specific elements (di Paolo et al., 2022b).

Future directions and practical implication

A recommendation for future research is to carry out almost the same research with a larger sample size, and change the following things to see a more clear difference between the groups. Firstly, because the observation of any other performer can have a beneficial effect on learning, it might be better to not train with a buddy. This way, the participants of the control group could not have improved their performance through vicarious learning. Furthermore, research has shown that practicing with a partner (dyad) results in a better retention and transfer assessments than individual practice (Shea et al., 1999). This partner is preferably a teammate, because due to social interaction and rivalry it might provide additional learning benefits and boost motivation (Granados & Wulf, 2007). In future research, it might therefore be interesting to test two participants at the same time. Moreover, vocal feedback can have a significant impact on learning (Dempsey et al.,2009). It might be interesting to add this to the instruction + visual feedback group to give this group even more tools to improve their performance. Finally, analysis on an individual level compared to on a group level could provide a more useful outcome, because every individual has another pattern of performance over time.

This study provides new information into the relationship between visual feedback and intrinsic motivation. Furthermore, it works towards an optimal way to improve joint load scores with the use of (visual) feedback. With the recommendations that are mentioned for future research, it is important to work towards this type of research on the field (di Paolo et al., 2022a). A significant barrier for transferring research into the biomechanical load response pathways from the lab to the field, is the difficulty to quantify biomechanical loads. This is mainly caused by the inability to precisely measure biomechanical data in an athlete’s natural surroundings during training and/or competition (e.g. a football pitch). However, recent events have shown that in the near future, such knowledge might be more readily available in applied sport settings (Verheul et al. 2020). For instance, full-body wireless inertial sensor suits (such as Xsens), have been demonstrated to be a valid and reliable way to simultaneously measure the kinematic information of all body segments outside the lab and already has the ability to estimate ground reaction force (GRF) and joint moments while performing stereotypical tasks like walking (Stetter et al., 2019). These suits can cause movement restriction and be uncomfortable, because of the multiple body worn devices. To overcome these problems, markerless motion capture methods are being developed. These methods might eventually make it possible to predict joint load metrics at various levels (Verheul et al., 2020). The combination of kinematics and GRF may eventually be used to estimate structure-specific loading and thus open the door to field-based measurements and monitoring of internal biomechanical loads.

Conclusion

This research aimed to identify the effect of visual instruction and feedback on joint loads and intrinsic motivation. Based on a repeated measures analysis, it can be concluded that time has an effect on joint loads score. The results indicate that joint load scores at the pretest were better than at the post-test and retention test, which means that the performance decreased after the training weeks. The better joint load scores at the pretest were thus not in line with the hypothesis. An explanation for these unpredicted results could be that the participants were less motivated in the last stage of the research. Furthermore, it can be concluded that time has an effect on intrinsic motivation. The results indicate that intrinsic motivation is higher at T3 compared to T1, which means intrinsic motivation increases between these time points. Further analysis into the cIMI subscales showed that participants of the instruction group put in less effort compared to the other two groups.

All in all, this research has shown how to measure joint loads and intrinsic motivation in the lab for different feedback groups. It gave insight into how intrinsic motivation and joint loads scores change over time. However, some results were not in line with the hypothesis. Future research should focus on improving the limitations of this study, such as analysing the data on an individual level, making a more clear difference between the groups and making this research transferable to the field for optimal results.

References

Benjaminse, A., Gokeler, A., Dowling, A. V., Faigenbaum, A., Ford, K. R., Hewett, T. E., Onate, J. A., Otten, B., & Myer, G. D. (2015). Optimization of the Anterior Cruciate Ligament Injury Prevention Paradigm: Novel Feedback Techniques to Enhance Motor Learning and Reduce Injury Risk. *Journal of Orthopaedic & Sports Physical Therapy*, *45*(3), 170–182. https://doi.org/10.2519/jospt.2015.4986

Benjaminse, A., & Verhagen, E. (2021, September 17). Implementing ACL Injury Prevention in Daily Sports Practice—It's Not Just the Program: Let's Build Together, Involve the Context, and Improve the Content. *Sports Medicine*, *51*(12), 2461–2467. https://doi.org/10.1007/s40279-021-01560-4

Boden, B. P., Dean, G. S., Feagin, J. A., & Garrett, W. E. (2000). Mechanisms of Anterior Cruciate Ligament Injury. *Orthopedics, 23(6)*, 573–578. https://doi.org/10.3928/0147-7447-20000601-15

Boden, B. P., Sheehan, F. T., Torg, J. S., & Hewett, T. E. (2010). Noncontact Anterior Cruciate Ligament Injuries: Mechanisms and Risk Factors. *American Academy of Orthopaedic Surgeon*, *18*(9), 520–527. https://doi.org/10.5435/00124635-201009000-00003

Carlson, V. R., Sheehan, F. T., & Boden, B. P. (2016). Video Analysis of Anterior Cruciate Ligament (ACL) Injuries. *JBJS Reviews*, *4*(11). https://doi.org/10.2106/jbjs.rvw.15.00116

Clark, S. E., & Ste-Marie, D. M. (2007, March). The impact of self-as-a-model interventions on children's self-regulation of learning and swimming performance. *Journal of Sports Sciences*, *25(5)*, 577–586. https://doi.org/10.1080/02640410600947090

Darby, A., Longmire-Avital, B., Chenault, J., & Haglund, M. (2013). Students' Motivation in Academic Service-Learning over the Course of the Semester. *College Student Journal*, *47*(1), 185–191.
https://www.tamiu.edu/profcenter/documents/StudentsMotivationinAcademicSL.pdf

Deci, E. L., & Ryan, R. M. (2000). The “What” and “Why” of Goal Pursuits: Human Needs and the Self-Determination of Behavior. *Psychological Inquiry*, *11*(4), 227–268. https://doi.org/10.1207/s15327965pli1104_01

Della Villa, F., Buckthorpe, M., Grassi, A., Nabiuzzi, A., Tosarelli, F., Zaffagnini, S., & Della Villa, S. (2020). Systematic video analysis of ACL injuries in professional male football (soccer): injury mechanisms, situational patterns and biomechanics study on 134 consecutive cases. *British Journal of Sports Medicine*, *54*(23), 1423–1432. https://doi.org/10.1136/bjsports-2019-101247

Dempsey, A. R., Lloyd, D. G., Elliott, B. C., Steele, J. R., & Munro, B. J. (2009). Changing Sidestep Cutting Technique Reduces Knee Valgus Loading. *The American Journal of Sports Medicine*, *37*(11), 2194–2200. https://doi.org/10.1177/0363546509334373

Di Paolo, S., Bragonzoni, L., Della Villa, F., Grassi, A., & Zaffagnini, S. (2022a). Do healthy athletes exhibit at-risk biomechanics for anterior cruciate ligament injury during pivoting movements? *Sports Biomechanics*, 1–14. https://doi.org/10.1080/14763141.2022.2080105

Di Paolo, S. S., Nijmeijer, E. M., Bragonzoni, L., Dingshoff, E., Gokeler, A., & Benjaminse, A. (2022b). Comparing lab and field agility kinematics in young talented female football players: Implications for ACL injury prevention. *European Journal of Sport Science*, 1–10. https://doi.org/10.1080/17461391.2022.2064771

Dix, C., Arundale, A., Silvers-Granelli, H., Marmon, A., Zarzycki, R., & Snyder-Mackler, L. (2021). Biomechanical Changes During a 90° Cut in Collegiate Female Soccer Players With Participation in the 11+. *International Journal of Sports Physical Therapy*, *16*(3). https://doi.org/10.26603/001c.22146

Eggerding, V., Reijman, M., Meuffels, D. E., van Es, E., van Arkel, E., van den Brand, I., van Linge, J., Zijl, J., Bierma-Zeinstra, S. M., & Koopmanschap, M. (2021). ACL reconstruction for all is not cost-effective after acute ACL rupture. *British Journal of Sports Medicine*, *56*(1), 24–28. https://doi.org/10.1136/bjsports-2020-102564

Ericksen, H. M., Thomas, A. C., Gribble, P. A., Doebel, S. C., & Pietrosimone, B. G. (2015).

Immediate Effects of Real-Time Feedback on Jump-Landing Kinematics. *Journal of Orthopaedic &Amp; Sports Physical Therapy*, *45*(2), 112–118. https://doi.org/10.2519/jospt.2015.4997

Granados, C., & Wulf, G. (2007). Enhancing Motor Learning Through Dyad Practice. *Research Quarterly for Exercise and Sport*, *78*(3), 197–203. https://doi.org/10.1080/02701367.2007.10599417

Hackshaw, A. (2008). Small studies: strengths and limitations. *The European Respiratory Journal*, *32*(5), 1141–1143. https://doi.org/10.1183/09031936.00136408

Hagger, M., Hardcastle, S., Chater, A., Mallett, C., Pal, S., & Chatzisarantis, N. (2014, January). Autonomous and controlled motivational regulations for multiple health-related behaviors: between- and within-participants analyses. *Health Psychology and Behavioral Medicine*, *2*(1), 565–601. https://doi.org/10.1080/21642850.2014.912945

Hagger, M. S., Sultan, S., Hardcastle, S. J., & Chatzisarantis, N. L. (2015). Perceived autonomy support and autonomous motivation toward mathematics activities in educational and out-of-school contexts is related to mathematics homework behavior and attainment. *Contemporary Educational Psychology*, *41*, 111–123. https://doi.org/10.1016/j.cedpsych.2014.12.002

Hill, Y., Meijer, R. R., Van Yperen, N. W., Michelakis, G., Barisch, S., & Hartigh, R. J. R. D. (2021). Nonergodicity in protective factors of resilience in athletes. *Sport, Exercise, and Performance Psychology*, *10*(2), 217–223. https://doi.org/10.1037/spy0000246

Holderness, C. G. (2016). Problems Using Aggregate Data to Infer Individual Behavior: Evidence from Law, Finance, and Ownership Concentration. *Critical Finance Review*, *5*(1), 1–40. https://doi.org/10.1561/104.00000028

Intrinsic Motivation Inventory (IMI) – selfdeterminationtheory.org. (n.d.). Retrieved October 18, 2022, from https://selfdeterminationtheory.org/intrinsic-motivation-inventory/

James, C. R., Herman, J. M., Dufek, J. S., & Bates, B. T. (2007). Number of trials necessary to achieve performance stability of selected ground reaction force variables during landing. *Journal of Sports Science and Medicine*. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3778688/

Leppänen, M., Pasanen, K., Kujala, U. M., Vasankari, T., Kannus, P., Äyrämö, S., Krosshaug, T., Bahr, R., Avela, J., Perttunen, J., & Parkkari, J. (2016). Stiff Landings Are Associated With Increased ACL Injury Risk in Young Female Basketball and Floorball Players. *The American Journal of Sports Medicine*, *45*(2), 386–393. https://doi.org/10.1177/0363546516665810

Lucarno, S., Zago, M., Buckthorpe, M., Grassi, A., Tosarelli, F., Smith, R., & Della Villa, F. (2021). Systematic Video Analysis of Anterior Cruciate Ligament Injuries in Professional Female Soccer Players. *The American Journal of Sports Medicine*, *49*(7), 1794–1802. https://doi.org/10.1177/03635465211008169

Mayes, J. (2015). Still to learn from vicarious learning. *E-Learning and Digital Media*, *12*(3–4), 361–371. https://doi.org/10.1177/2042753015571839

McAuley, E., Duncan, T., & Tammen, V. V. (1989, March). Psychometric Properties of the Intrinsic Motivation Inventory in a Competitive Sport Setting: A Confirmatory Factor Analysis. *Research Quarterly for Exercise and Sport*, *60*(1), 48–58. https://doi.org/10.1080/02701367.1989.10607413

McNevin, N. H., Wulf, G., & Carlson, C. (2000). Effects of Attentional Focus, Self-Control, and Dyad Training on Motor Learning: Implications for Physical Rehabilitation. *Physical Therapy*, *80*(4), 373–385. https://doi.org/10.1093/ptj/80.4.373

Molinaro, J (2014). *Lang's injury sad end to inspiring story. Sportsnet.Ca*. Retrieved 11 May 2022, from https://www.sportsnet.ca/soccer/langs-injury-sad-end-to-inspiring-story/

Nexus | Software For Motion Capture In Life Sciences. (2022, August 30). Vicon. Retrieved October 11, 2022, from https://www.vicon.com/software/nexus/

Neumann, N., Van Yperen, N. W., Brauers, J., Frencken, W., Brink, M., Lemmink, K. A., Meerhoff, R., & Hartigh, R. J. R. D. (2022). Nonergodicity in Load and Recovery: Group Results Do Not Generalize to Individuals. *International Journal of Sports Physiology and Performance, 17*(3), 391–399. https://doi.org/10.1123/ijspp.2021-0126

Onate, J. A., Guskiewicz, K. M., & Sullivan, R. J. (2001). Augmented Feedback Reduces Jump Landing Forces. *Journal of Orthopaedic &Amp; Sports Physical Therapy*, *31*(9), 511–517. https://doi.org/10.2519/jospt.2001.31.9.511

Pfeifer, C, et al., (2018). RISK FACTORS ASSOCIATED WITH NON-CONTACT ANTERIOR CRUCIATE LIGAMENT INJURY: A SYSTEMATIC REVIEW. *Int J Sports Phys Ther. 2018 Aug;13*(4):575-587 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6088120/

Sanli, E. A., Patterson, J. T., Bray, S. R., & Lee, T. D. (2013). Understanding Self-Controlled Motor Learning Protocols through the Self-Determination Theory. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00611

Shea, C. H., Wulf, G., & Whltacre, C. (1999). Enhancing Training Efficiency and Effectiveness Through the Use of Dyad Training. *Journal of Motor Behavior*, *31*(2), 119–125. https://doi.org/10.1080/00222899909600983

Silvers-Granelli, H. J. (2021). Why Female Athletes Injure Their ACL’s More Frequently? What can we do to mitigate their risk? *The International Journal of Sports Physical Therapy*, *16*(4). https://doi.org/10.26603/001c.25467

Singh, H., Gokeler, A., & Benjaminse, A. (2021). Effective Attentional Focus Strategies after Anterior Cruciate Ligament Reconstruction: A Commentary. *The International Journal of Sports Physical Therapy*, *16*(6). https://doi.org/10.26603/001c.29848

Stetter, B. J., Ringhof, S., Krafft, F. C., Sell, S., & Stein, T. (2019). Estimation of Knee Joint Forces in Sport Movements Using Wearable Sensors and Machine Learning. *Sensors*, *19*(17), 3690. https://doi.org/10.3390/s19173690

Verheul, J., Nedergaard, N. J., Vanrenterghem, J., & Robinson, M. D. (2020). Measuring biomechanical loads in team sports – from lab to field. *Science & Medicine in Football*, *4*(3), 246–252. https://doi.org/10.1080/24733938.2019.1709654

Voskanian, N. (2013). ACL Injury prevention in female athletes: review of the literature and practical considerations in implementing an ACL prevention program. *Current Reviews in Musculoskeletal Medicine*, *6*(2), 158–163. https://doi.org/10.1007/s12178-013-9158-y

Withrow, T. J., Huston, L. J., Wojtys, E. M., & Ashton-Miller, J. A. (2006). The Relationship between Quadriceps Muscle Force, Knee Flexion, and Anterior Cruciate Ligament Strain in an in Vitro Simulated Jump Landing. *The American Journal of Sports Medicine*, *34*(2), 269–274. https://doi.org/10.1177/0363546505280906

Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *International Review of Sport and Exercise Psychology*, *6*(1), 77–104. https://doi.org/10.1080/1750984x.2012.723728

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, *23*(5), 1382–1414. https://doi.org/10.3758/s13423-015-0999-9

Wulf, G., Shea, C., & Lewthwaite, R. (2010). Motor skill learning and performance: a review of influential factors. *Medical Education*, *44*(1), 75–84. https://doi.org/10.1111/j.1365-2923.2009.03421.x

Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin*, *67*(4), 304–309. https://doi.org/10.1016/j.brainresbull.2005.06.035

Zusho, A., Pintrich, P. R., & Coppola, B. P. (2010). Skill and will: The role of motivation and cognition in the learning of college chemistry. *International Journal of Science Education*, *25*(9), 1081–1094. https://doi.org/10.1080/0950069032000052207

Appendix A

Sidestep cutting exercise setup for every week

Side step
cut
Baseline/
immediate
post/
retention

12 red cones

Side step
cut
week 1

12 red cones

Side step
cut
week 2

14 red cones
2 green cones

Side step
cut
week 3

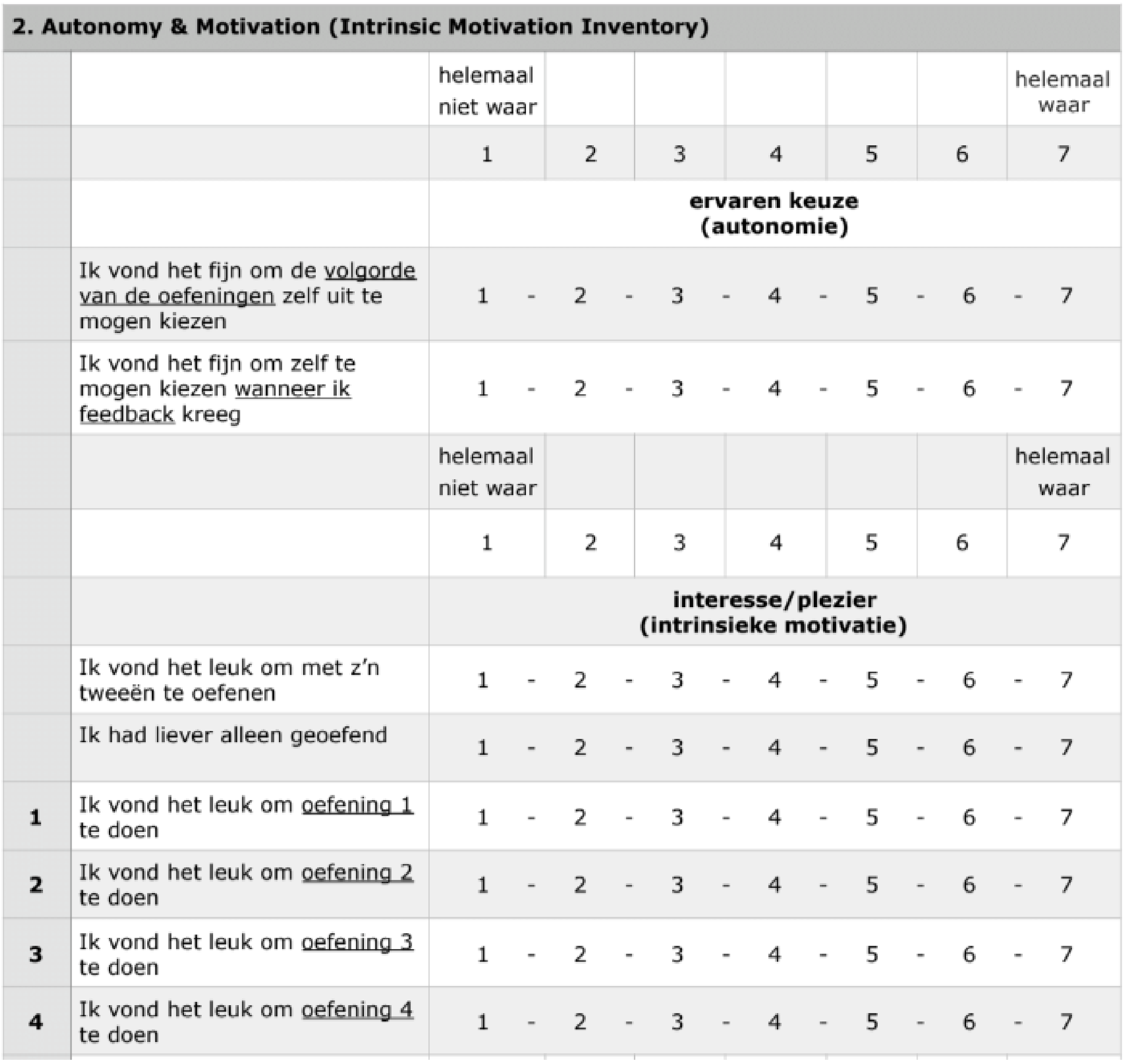
14 red cones
2 green cones
2 balls
2 boxes

Side step
cut
week 4

2 red cones
2 balls
2 boxes
Swift speed
light

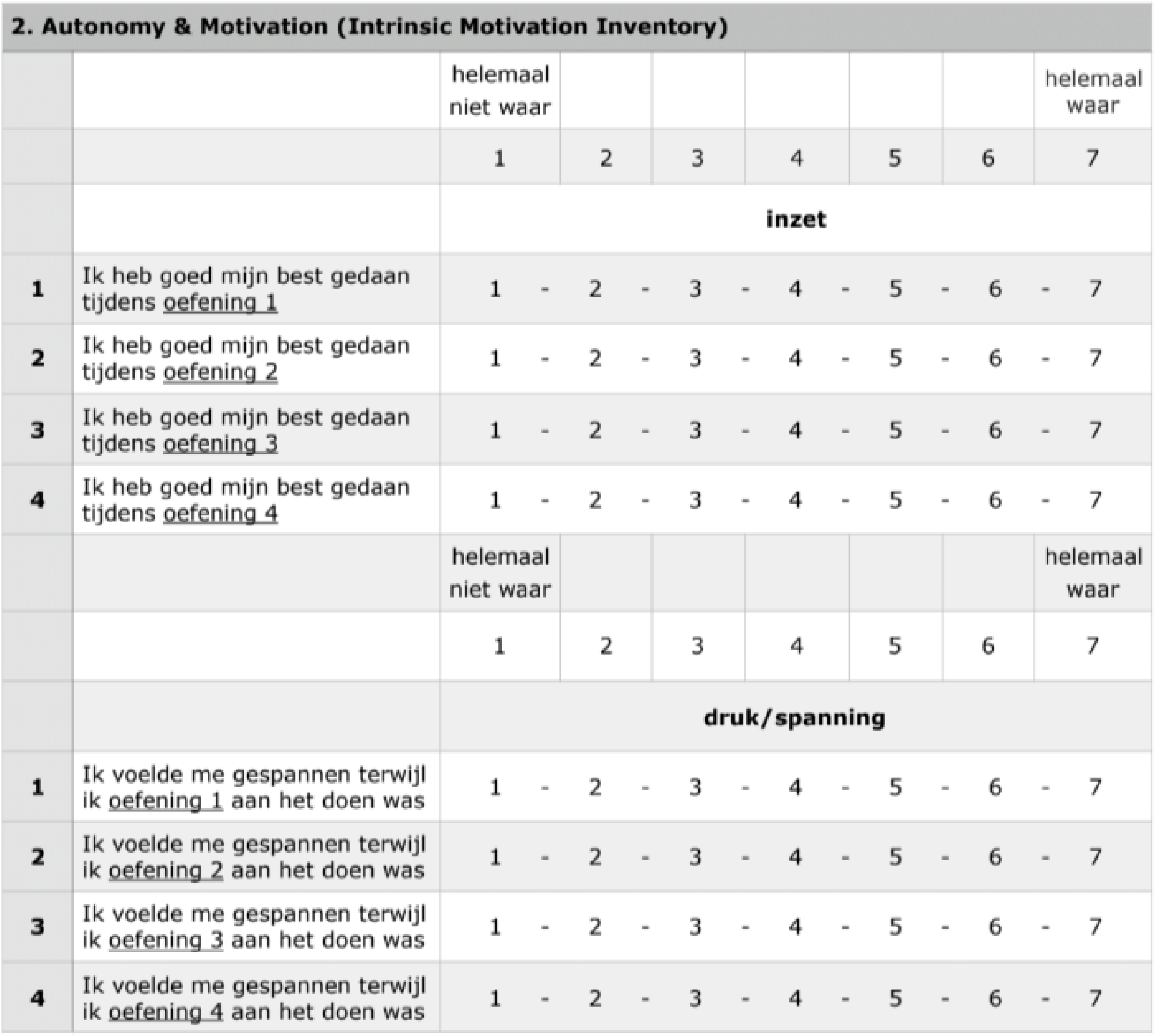
Appendix B

Composed Intrinsic Motivation Inventory (cIMI)



2. Autonomy & Motivation (Intrinsic Motivation Inventory)								
		helemaal niet waar						helemaal waar
		1	2	3	4	5	6	7
		ervaren keuze (autonomie)						
	Ik vond het fijn om de volgorde van de oefeningen zelf uit te mogen kiezen	1 -	2 -	3 -	4 -	5 -	6 -	7
	Ik vond het fijn om zelf te mogen kiezen wanneer ik feedback kreeg	1 -	2 -	3 -	4 -	5 -	6 -	7
		helemaal niet waar						helemaal waar
		1	2	3	4	5	6	7
		interesse/plezier (intrinsieke motivatie)						
	Ik vond het leuk om met z'n tweeën te oefenen	1 -	2 -	3 -	4 -	5 -	6 -	7
	Ik had liever alleen geoefend	1 -	2 -	3 -	4 -	5 -	6 -	7
1	Ik vond het leuk om oefening 1 te doen	1 -	2 -	3 -	4 -	5 -	6 -	7
2	Ik vond het leuk om oefening 2 te doen	1 -	2 -	3 -	4 -	5 -	6 -	7
3	Ik vond het leuk om oefening 3 te doen	1 -	2 -	3 -	4 -	5 -	6 -	7
4	Ik vond het leuk om oefening 4 te doen	1 -	2 -	3 -	4 -	5 -	6 -	7

		ervaren competentie						
1	Ik denk dat ik vrij goed ben in oefening 1	1 -	2 -	3 -	4 -	5 -	6 -	7
2	Ik denk dat ik vrij goed ben in oefening 2	1 -	2 -	3 -	4 -	5 -	6 -	7
3	Ik denk dat ik vrij goed ben in oefening 3	1 -	2 -	3 -	4 -	5 -	6 -	7
4	Ik denk dat ik vrij goed ben in oefening 4	1 -	2 -	3 -	4 -	5 -	6 -	7



2. Autonomy & Motivation (Intrinsic Motivation Inventory)

		helemaal niet waar						helemaal waar
		1	2	3	4	5	6	7
		inzet						
1	Ik heb goed mijn best gedaan tijdens oefening 1	1 -	2 -	3 -	4 -	5 -	6 -	7
2	Ik heb goed mijn best gedaan tijdens oefening 2	1 -	2 -	3 -	4 -	5 -	6 -	7
3	Ik heb goed mijn best gedaan tijdens oefening 3	1 -	2 -	3 -	4 -	5 -	6 -	7
4	Ik heb goed mijn best gedaan tijdens oefening 4	1 -	2 -	3 -	4 -	5 -	6 -	7
		helemaal niet waar						helemaal waar
		1	2	3	4	5	6	7
		druk/spanning						
1	Ik voelde me gespannen terwijl ik oefening 1 aan het doen was	1 -	2 -	3 -	4 -	5 -	6 -	7
2	Ik voelde me gespannen terwijl ik oefening 2 aan het doen was	1 -	2 -	3 -	4 -	5 -	6 -	7
3	Ik voelde me gespannen terwijl ik oefening 3 aan het doen was	1 -	2 -	3 -	4 -	5 -	6 -	7
4	Ik voelde me gespannen terwijl ik oefening 4 aan het doen was	1 -	2 -	3 -	4 -	5 -	6 -	7