New taxonomy for assessing manual material handlers' footstep patterns

Jasmin Vallée Marcotte[a,b], Antoine Muller[c], Xavier Robert-Lachaine[a,b,c], Véronique Fecteau[a], Denys Denis[d], André Plamondon[c], Philippe Corbeil[a,b]

[a] Department of kinesiology, Université Laval, Québec, Québec, Canada

[b] Centre interdisciplinaire de recherche en réadaptation et intégration sociale (CIRRIS), Centre intégré universitaire de santé et de services sociaux de la Capitale-Nationale (CIUSSS-CN), Québec, Canada

[c] Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), 505 boul. De Maisonneuve Ouest, Montréal, Québec, Canada H3A 3C2

[d] Université du Québec à Montréal (UQAM), Montréal, Québec, Canada

Corresponding authors:

Philippe Corbeil PhD, 2300 Rue de la Terrasse, Université Laval, Quebec City, QC, G1V 0A6, Canada. E-mail address: Philippe.corbeil@kin.ulaval.ca

Jasmin Vallée Marcotte, MA. 2300 Rue de la Terrasse, Université Laval, Quebec City, QC, G1V 0A6, Canada.

E-mail address: jasmin.vallee-marcotte.1@ulaval.ca

Abstract

Current taxonomies for assessing foot strategies in manual material handling lack exhaustive classification of foot movements and foot positioning. They also fail to consider different instants of the task as checkpoints to relate foot strategies. The goal of the study was first to develop a new taxonomy to assess foot positions and motions considering those limitations. The second goal was to assess reliability and reproducibility using raw agreement percentages, Cohen's kappa, prevalence-adjusted, bias-adjusted kappa and Gwet's AC1. A filmed task consisted of transferring boxes from one pallet to another. Intra- and inter-rater reliability were assessed reviewing 23% and 10%, respectively, of video data. Reproducibility and reliability results are substantial and almost perfect on average. In comparison to similar studies, reproducibility and reliability were considered acceptable.

Highlights

- A taxonomy was developed to assess foot strategies in manual material handling
- Intra- and inter-rater reliability were satisfactory
- The taxonomy allows interpretation of handlers' strategies

Keywords: Footstep strategies, step, classification

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1. Introduction

Low back pain is the principal disability factor in terms of years lived with disability; the worldwide prevalence is 9.4% (Hoy et al., 2014). Manual material handling (MMH) tasks present many risk factors for low back pain (Bernard and Putz-Anderson, 1997; da Costa and Vieira, 2010; Kuiper et al., 1999; Marras et al., 1993). Consequently, handlers are taught lifting techniques in an attempt to reduce the impact of physical stress on the back. Those techniques often promote squatting over stooping or leg lifting (Sedgwick and Gormley, 1998; Verbeek et al., 2012); their effectiveness is only limited (Kuorinka et al., 1994; Martimo et al., 2008; Verbeek et al., 2012). Ergonomic studies show that MMH techniques involve numerous components such as hand placement, pelvis orientation and foot positioning (Authier et al., 1995; Authier et al., 1996; Kuorinka et al., 1994; Lortie, 2002).

Among the various components (feet, box grip, pelvis orientation, etc.) that compose a handling strategy, the role of foot positioning and footstep strategies has been addressed in several studies. For instance, Authier et al. (1995; 1996) observed differences between how novice and expert handlers position and move their feet during the lifting, transferring and depositing of boxes. During the lift and deposit, experts tend to position their feet closer to the pickup or deposit location more often than novices. For the transfer, they found differences in foot pivoting, angle between feet and number of foot supports. In complementary studies, Delisle et al. (1996; 1999) showed the impact on trunk kinematics of different stepping patterns during the transfer. They found that stepping toward the deposit location during transfer could reduce posture asymmetry. In addition, some studies have shown that foot placements and movements mainly affect posture and movements of the whole body but influence loading of the back as well (Kingma et al., 2004; Plamondon et al., 2006). However, one limitation on these protocols is that they impose a specific position or movement rather than letting handlers choose their own technique.

Considering the importance of certain foot positions and motions, a classification is necessary to document them since to date no exhaustive documentation of those strategies has existed. Wagner et al. (2009; 2010) developed a qualitative approach to describe foot position and motion called the lexical transition classification system (L-TRACS). This taxonomy assigns foot positioning at the point of load lifting into three categories: split stance (feet spread apart) with ipsilateral foot, or contralateral foot as leading foot and even stance (feet side by side). It also assesses stepping behaviors before and after load lifting. After observing automotive assembly operators, they proposed four classes of steps: progression step, pivot step, orient step and move step.

There are some limitations affecting the L-TRACS method (Table 1). First, the move step class does not describe a particular movement performed by the worker. Instead, this class includes movements that do not respect the criteria to be classified as one of the other three step classes. For instance, both a backward movement of the foot without reorientation and a small step with substantial reorientation would be classified as a move step because they do not meet the criteria for the other categories. Hence, foot motion cannot be fully described by the taxonomy. A second limitation is that no movement information is given by the terminal stance state. The stance indicates the position of the feet and whether or not heels and/or toes are in contact with the ground. However, the dynamic or static state of the feet during lifting and the type of movement (if any) are unknown. Nevertheless, it has been observed that handlers may move their feet during the lifting phase (Denis et al., 2013). A third limitation is that the taxonomy assumes that the handler is facing the job while picking up the load. However, several studies have shown that the handler may be oriented toward the deposit area during lifting (Authier et al., 1995; Authier et al., 1996; Baril-Gingras and Lortie, 1995). Therefore, the taxonomy does not consider the orientation of the feet relative to the lifting location. A fourth limitation is that the taxonomy does not identify strategies according to specific checkpoints throughout the task. The movements and positions of the handler’s feet are observed before, during and immediately after picking up the load. However, ergonomic studies generally assess the handler's strategies at specific points throughout the process: lifting, transition and deposit (Authier et al., 1995; Authier et al., 1996; Plamondon et al., 2014).

Those limitations prevent researchers from fully documenting handlers' foot placement and movement strategies. Hence, there is a need for a taxonomy inspired by previous work that considers two important elements. First, it requires a more exhaustive characterization of foot placement and movement strategies. This element addresses the three first issues affecting Wagner et al.'s method. Second, it needs to consider key instants of the handling task from load lifting to deposit. Indeed, MMH tasks include certain key actions. It is therefore important to relate foot movements to these checkpoints in order to fully comprehend handlers' strategies. The foot placement and movements strategies used in MMH are still unknown. It is, however, necessary to document the different strategies that can be used during an MMH task. Therefore, a taxonomy that overcomes the limitations of the L-TRACS is necessary. The goal of this study was to develop and validate a taxonomy inspired by the L-TRACS to characterize foot placement and movements during the lifting, transfer and deposit phases of MMH.

< Insert Table 1 about here >

2. Methods

2.1 Taxonomy

The handling task cycle was divided into four instants: first contact, lifting, pre-deposit (arrival) and deposit (Figure 1A, Appendix 1). The first contact instant is when the subject's hand first comes into contact with the box. The lifting instant is the point when the box is no longer in contact with the supporting surface. In other words, the handler is supporting the full weight of the box. The pre-deposit instant was identified as when the handler arrives at the deposit pallet. Two criteria must be respected to identify the pre-deposit instant. First, one foot must arrive at the deposit location. For one foot to be considered to have “arrived,” the second foot must not be more than half a foot length closer, if this second foot gets closer to the deposit location than the first one. Second, the handler must start to initiate the deposit of the box. This is observed when the upper arms are moving up or when the trunk is bending. The deposit instant was identified as the point when the box touches the surface. At that time, the handler is no longer supporting the whole weight of the box.

Those four instants divide the handling cycle into three phases: preparation, transfer and lowering. Phases are not brief instants but temporal windows.

< Insert Figure 1 about here >

The taxonomy expresses the positions and movements of the feet during the entire handling cycle. At the four instants, an element of position and movement is assigned. During the transfer phase, only an element of movement is assigned to identify patterns in the succession of steps. There is no position element for the transfer phase because numerous steps are taken during that phase and it may not be relevant to interpret them all.

2.1.1 Foot position classification

There is a stance for position of the feet at each of the four instants of the handling task. The position of the feet is coded into one of five position types (Table 2, Figure 1B, Figure 2, Appendix 2). Position types were defined according to the placement of the feet relative to the pallet and box, as well as body rotation. For the first contact and lifting instants, the pallet referred to is the lifting pallet. For the pre-deposit and deposit instants, the pallet referred to is the deposit pallet. Foot position depends on the movement that is performed by the handler at the four instants. If no movement is performed when the instant occurs, the position stance refers to the position of the feet at that point. On the other hand, if there is a movement when the instant occurs, the position stance refers to the position of the feet preceding the movement. It is possible to observe crossovers between even, contralateral/ipsilateral foot forward and parallel stances. For instance, one foot could be behind the other {Contralateral/ipsilateral foot forward} but the feet are not directly facing the pallet {parallel stance}. In those cases, certain criteria must be checked to choose the correct position stance (Table 2).

< Insert Table 2 and Figure 2 about here >

2.1.2 Foot motion classification

At each of the four instants of the handling task, there is a foot movement stance (Table 3, Appendix 2 & 3). For first contact, lifting, pre-deposit and deposit, stance refers to a single type of movement that is performed when the instant occurs. In addition, stance for the transfer phase differs from during the instants. During the instants, a single movement of one foot may occur (Table 3). During the transfer phase, stance refers to a succession of steps that represents the type of strategy used by the handler (Table 4).

< Insert Tables 3 and 4 about here >

Foot positions and movements are described by a sequence (S). A sequence is defined as the combination of positions and movements at each instant of one trial. Using commas, a sequence is divided into four terminal stances, one for each of the four instants, and the transfer (phase). For each terminal stance, there is a position and a movement (code) stance. The exception is the transfer phase, where there is no position stance but only a movement stance. Thus, there are nine variables that describe foot positions and movements from first contact with the box to deposit. A sequence would be expressed as: $S = \{P_{M,}\ P_M, T_M, P_M, P_M\}$, where {P} refers to a position stance, {M} to a movement stance and {T} to the transfer phase. An example of a sequence would be the following: $S = \{E_{N\text{-}M}, E_{P\text{-}T}, T_O, S_{N\text{-}M}, E_{N\text{-}M}\}$ (Figure 3). In this example, the subject touches the box in an even stance position with no movement ({E} meaning even stance and {$_{N\text{-}M}$} meaning no movement). At the time of lifting, the subject performs a translation and rotation movement

{$E_{P\text{-}T}$}. In the transfer phase {T}, the handler performs an open turn {O}. At pre-deposit, the handler is in Contralateral foot forward position, feet not moving {$S_{N\text{-}M}$}. After pre-deposit but before the deposit instant, the handler has moved his/her feet to be in an even stance position with no movement at the instant of deposit {$E_{N\text{-}M}$}.

< Insert Figure 3 about here >

2.2 Reliability and reproducibility

2.2.1 Subjects

Data for this study were taken from the work of (Plamondon et al., 2014). Thirty male subjects with various degrees of experience (from less than one year to more than 20 years) in manual material handling were recruited. All participants gave informed consent by completing a form approved by the Ethics Committee of the University of Sherbrooke (Faculty of Medicine and Health Science).

2.2.2 Experimental protocol

The task consisted in transporting 24 boxes weighing 15 kg from one pallet to another. Subjects transferred all 24 boxes continuously, one after the other. They then moved the boxes back to the first pallet. This was repeated five times over a period of 30 minutes, thus totaling 240 transfers. Two out of five trips were performed at a pace-free rhythm to represent a regular 8-hour working day. The other three trips were performed at a pace of nine boxes per minute to increase the challenge and fatigue. There was a rest period lasting a maximum of 5 minutes between the last non-paced and the first paced trial.

Boxes were initially positioned on the pallet in the following configuration: 3 boxes long, 4 boxes high and 2 boxes deep. Their dimensions were 35 cm wide by 32 cm high by 26 cm deep. Pallets were 16 cm high, located 1.5 m apart and were positioned 180° from each other.

2.2.3 Measuring systems

Three video cameras were used to film the task from three different angles. The videos were used to carry out ergonomic analyses and develop the taxonomy.

2.2.4 Instructions

There was no specific order in which the boxes had to be picked or placed. Participants were instructed to use techniques that they normally use at work. No further instructions were given on how to proceed during the task. However, participants had to stand on the force platform (1.90 m x 1.40 m) at all times.

2.2.5 Statistical analysis

A total of 60 trials per participant were observed using the taxonomy, totaling 1794 handling cycles (6 trials were discarded because the handlers did not respect the handling instructions). Only transfers on the “outbound” trip were analyzed for this study. Intra- and inter-rater reliability were assessed according to the nine variables composing the sequence. Two students in ergonomics assessed reliability. The first rater contributed to the development of the taxonomy. Intra-rater reliability was assessed by re-observing 23% of all data (414 transfers) in randomized order. Re-observations were performed at least one month after the first observation. Only the first rater was involved intra-rater reliability assessment. The taxonomy was taught to the second rater in a 2-hour session by the first rater. Criteria for identifying all instants and position and movement stances during all instants and the transfer phase were explained to the second rater. Visual examples of all instants and position and movement stances were provided to facilitate the understanding of the taxonomy. The second rater’s rating process was supported by answering questions about the taxonomy itself but not about the strategies used by handlers or the time of occurrence of each instant. Inter-rater reliability was assessed with the second rater observing 10% of data from the pace-free trips. For one of the two trips in that condition, six transfers (three transfers from the highest height and three from the lowest) per subject were observed in randomized order.

Percentages of agreement and kappas (Cohen, 1960) were calculated for each of the four instants and the transfer phase of the handling task, as these are the most common measures used to compare raters. Kappa statistically tests rates of agreement against the probability of rating randomly. However, this measure is affected by prevalence, which will give low kappa values if two raters are in high agreement (Feinstein and Cicchetti, 1990). Therefore, prevalence-adjusted, bias-adjusted kappa (PABAK) (Byrt et al., 1993) was also calculated since it is a common value used to complement kappas. However, it assumes that the prevalence is 50% instead of testing ratings against randomness. Hence, Gwet's AC1 measure was also calculated (Wongpakaran et al., 2013). An 80% percentage of agreement was considered sufficient (Denis et al., 2000; Nurjannah and Siwi, 2017). A kappa value below 0.00 was considered to indicate poor agreement; 0.00 to 0.20, slight; 0.21 to 0.40, fair; 0.41 to 0.60, moderate; 0.61 to 0.80, substantial; and 0.81 to 1.00, almost perfect (Landis and Koch, 1977). Median, mean, maximum and minimum values were calculated for percentages of agreement, kappa, PABAK and AC1. Confidence intervals with 95% bounds were calculated for kappa, PABAK and AC1. General results for terminal stances at each instant, the transfer and all different sequences were counted.

3. Results

3.1 Intra-rater reliability

The mean and median percentages of intra-rater agreement were 0.90 and 0.92, respectively (Table 5). The highest intra-rater percentage of agreement was observed on the movement stance during the pre-deposit instant (0.99), and the lowest intra-rater percentage of agreement was the movement stance during the lifting instant (0.80). Kappa, PABAK and AC1 range from 0.00 to 0.83, from 0.55 to 0.98, and from 0.72 to 0.99, respectively. The 0.00 kappa value was attributed to the movement stance during the pre-deposit phase. Since percentage of agreement and AC1 are 0.99 and PABAK is 0.98, this low kappa value must have been caused by the prevalence effect (Byrt et al., 1993).

< Insert Table 5 about here >

3.2 Inter-rater reliability

The mean and median percentages of inter-rater agreement were 0.75 and 0.77, respectively. Of the four instants and the transfer, the deposit instant was the one for which the percentage of agreement was the highest (0.86). Conversely, pre-deposit was where the percentage was the lowest (0.62).The highest inter-rater percentage of agreement was for the movement stance during the deposit instant (0.89), while the lowest inter-rater percentage of agreement was attributed to the movement stance during the pre-deposit instant (0.52).

Kappa, PABAK and AC1range from 0.01 to 0.71, 0.05 to 0.78, and 0.47 to 0.88, respectively. For the PABAK and AC1 coefficients, the highest value was for the movement stance during deposit. The lowest kappa, PABAK and AC1 were attributed to the movement stance at the pre-deposit phase.

3.3 Application of the taxonomy

There are multiple ways to present the taxonomy. Terminal stances can be assessed individually to focus on specific instants or phases (Table 6). For instance, the mean frequencies of movement usage for each instant were as follows: first contact: 3%; lifting: 50%; pre-deposit: 2%; and deposit: 5%.

The taxonomy can be also be presented in light of the phases that compose each handling cycle as well as in whole sequences (Table 7). Transitions between phases can also be identified.

< Insert Tables 6 and 7 about here >

4. Discussion

The objective of this study was to develop and assess the reproducibility of a taxonomy for assessing foot positions and displacements throughout a task while considering the relative position of the handler in relation to the pickup/deposit locations. Both intra- and inter-rater reliability were satisfactory. Furthermore, the results show that one can observe the different movements performed at each instant of the handling task. Those movements can be associated with a strategy performed by the handlers throughout the task.

4.1 Intra- and inter-rater validity

All percentages of agreement for intra-rater reliability were sufficient (> 80%), according to Denis et al. (2000). PABAK and AC1 values range respectively from moderate to almost perfect and from substantial to almost perfect agreement. Denis et al. (2002) obtained relatively similar results in the classification of movements in an MMH task designed to assess the importance of experience and training among raters. In that study, there were eight categorical variables related to foot position and orientation. For those variables, intra-rater percentages of agreement ranged from 68% to 99%, depending on the level of training and practice. Kappas ranged from moderate to almost perfect agreement. Of all variables (including non-foot-related variables), the mean percentages of agreement ranged from 82% to 85% (depending on training) while kappas showed substantial agreement. This study shows similar results to those of Denis et al. (2002). Other ergonomic studies that did not assess foot motions also obtained similar results. Palm et al. (2016) assessed intra-rater reliability for the evaluation of upper body movement in a cashier job. In their study, raters had to count the instances of specific movements according to certain criteria. Some movements were relatively gross and others finer. For instance, raters had to count the number of groceries handled using wrist movements (> 15°). They also assessed whether cashiers were standing or sitting. Using PABAK for intra-rater reliability, they obtained results ranging from 0.47 to 1.00. The authors considered those results to be acceptable; they have a similar range to the results from this study. In the light of the results of comparable studies, this study's intra-rater reliability seems acceptable since it produced similar results.

Percentages of inter-rater agreement were adequate for the lifting and deposit phases. None of the other percentages reached 80% agreement, although the AC1 values showed a substantial agreement between raters (0.71–0.76). Wagner et al. (Wagner et al., 2009) obtained lower agreement results assessing L-TRACS behavior, terminal stance and number of steps (K = 0.326–0.557; Table 8). This could indicate that the observations are difficult to make due to the complexity of the task. Not only are there multiple choices of positions and movement stances but position crossovers can occur; a handler may be in a position that corresponds not just to one position stance but to two or three at a time. Although the taxonomy addresses this issue, raters could become confused. Furthermore, handlers can use many different strategies. Therefore, although the task itself can be repetitive, the strategies are not necessarily repeated. Hence, the multiple possibilities for interpretation of the various movements can cause errors during the classification process. The time at which each phase occurs could also have caused discrepancy among raters as they had to judge these points by themselves. In particular, the instant when the pre-deposit phase occurs could have been difficult to assess, because of the multiple criteria that determine when that phase occurs.

< Insert Table 8 about here >

Inter-rater reliability coefficients are lower than intra-rater reliability, a phenomenon that was also mentioned by Denis et al. (2000). One factor to which this could be attributed is that the teaching of the taxonomy may not have been optimal. During the training, the taxonomy was presented in detail. However, the visual examples given may not have adequately and fully represented position or movement stances. Moreover, there was only one teaching session so the rater's experience with strategy assessment was limited. Those limitations could have altered the rater's overall interpretation of the position and movement stances assumed by the handlers. In addition, criteria to correctly identify every instant and position and movement stance were taught in detail. However, there was no procedure to test the second rater's understanding of the taxonomy. Therefore, there is no way to verify whether bias was present or not. A second cause could be that the first rater had more experience than th [illegible] The first rater viewed all the data while the second rater observed 10% of it. Therefore, the second rater may not have assessed the data in as much in detail as the first one.

4.2 Benefits of the taxonomy

This taxonomy was developed to assess foot positions and movements at four instants and one phase of a lifting task. Evaluating strategies without considering both positions and movements at key instants during a task will result in a loss of information about handlers' strategies. Authier et al. (1996) described foot positioning as a significant execution parameter for ergonomic studies. For instance, some handlers do not stand in front of the pickup location while lifting. This taxonomy addresses Wagner et al.'s (2009; 2010) issue concerning foot positioning but also describes movements more exhaustively. In this way, one can assess whether the handler's feet are dynamic or static at key instants during the box transfer and describe the movements. The results showed that handlers moved their feet in 50% of transfers during lifting tasks. In this case, not describing foot movements would lead to a loss of information concerning strategies in half of the observed trials. The transfer phase is also important to consider, as Delisle et al. (1999) showed that foot motions during the transfer of a box have an impact on asymmetry of posture. The results from this study show that movements rarely occur during the contact and arrival instants. Moreover, those instants are also where agreement values are the lowest. Although this could lead to a loss of precision, a trade-off could be made to lighten the taxonomy by providing fewer elements to assess.

Another benefit of the taxonomy is that it allows users to assess a handler's strategy throughout the entire task. Wagner et al.'s (2009) method is more oriented toward the description of each footstep in the handling task without specific information on exactly when each step occurs. In comparison, this taxonomy comprises sequences composed of four instants and one phase. As shown by Authier et al. (1995; 1996), dividing the task into segments allows one to draw conclusions about the strategies used at each step of the task. The first contact with the box reveals the handler's strategy to prepare for lifting. The handler needs to prepare for the transition from lifting to deposit (Denis et al., 2013). Positioning the feet appropriately before lifting allows the handler to correctly execute the chosen strategy. Moreover, the transfer complements the strategy used at lifting but also indicates the strategy adopted during transition.

One strategy frequently applied by handlers was {Parallel, ipsilateral–Pivot-translation} during lifting followed by an {Open turn}. In this example, the {Parallel, ipsilateral} stance could facilitate a quick transition since the feet are more oriented toward the deposit location, unlike an {Even stance}. Furthermore, the {Pivot-translation} movement is followed by an {Open turn}. This indicates that the handlers started moving toward the deposit location at the instant of lifting instead of in the transfer phase. This strategy shows a certain fluidity in the succession of movements during handling (Authier et al., 1995; Denis et al., 2013; Lortie, 2002). A counterexample of that strategy would be an {Even stance–No movement} followed by a {Progressive turn}. In this case, handlers instead choose a more symmetrical lift and a slower transfer to ensure balance and symmetry (Authier et al., 1995; Denis et al., 2013; Lortie, 2002). The arrival and deposit instants provide information about lowering strategies. As with the preparation and transition phases, handlers may favor a faster lowering or a more gradual one. For example, one strategy that was used is {Contralateral foot forward–No movement} at the arrival and {Even stance–No movement} at the deposit. In this case, no movement is performed at either instant but the position changes from the contralateral foot in front of the ipsilateral one to an {Even stance}. This suggests that the handlers were still walking during the lowering motion, reflecting a certain fluidity in their movements. Considering those instants helps researchers draw conclusions about the general strategies used by handlers.

4.3 Limits of the taxonomy

This taxonomy was developed to be applicable to a wide range of working contexts. However, it was based on observation of only one handling task. More specifically, the position of the pickup location in relation to the deposit point (180°) was the same for every observation. This an important factor to consider since foot positioning strategies depend on it (Authier et al., 1996).

Another limitation is that the handlers performed the task in a laboratory context. Handlers did not receive instructions on how to do the task. However, the laboratory context could have affected how they performed the handling task. Subjects had Optotrak LEDs attached to their body, which could have interfered with their movements. In addition, the lack of familiarity with the laboratory setup may have affected their behaviors (Faber et al., 2011). Moreover, the cameras were not positioned specifically so as to view handlers' feet during the task. Consequently, at least one of the feet was hardly visible because it was hidden by the other foot most of the time. The darkness in the room also made observation more difficult. Despite this issue, the results showed good intra- and inter-rater reliability.

Another limit on this taxonomy is that the movement stances do not always reveal whether the moving foot is ipsilateral or contralateral to the turning direction, except for the {pivot-translation} move. This was because that is how the stances were defined. No {Pivot-translation} was observed for the contralateral foot during the observations. Instead, they were classified as {Pivot} or {Backward translation}. The reason for this limitation was simplification. Considering whether the moving foot was ipsilateral or not would have resulted in almost twice as many possible movement stances. To reduce the number of classifications, we chose not to consider this parameter.

5. Conclusion

In this paper, we developed a taxonomy for assessing foot movement and position throughout an MMH task, based on the method suggested by Wagner et al. (2009). This method showed sufficient intra-rater reliability and moderate inter-rater reliability. Finally, it addresses the limits of existing methods by considering the position of the feet in relation to the environment and their movements. It also takes account of the points in the handling task when the strategies are used, thereby providing benchmarks to better understand and compare handlers' behaviors. Thus, it allows a more precise assessment of foot strategies in MMH studies. A better understanding of foot strategies could improve ergonomic evaluations and workers' training. Sensor-based monitoring (e.g., using wearable sensors, load tiles, computer vision analysis etc.) to support development and analysis of this taxonomy could be beneficial in the future.

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Table 1: Key differences of Wagner et al.'s transition classification system and proposed approach

	Wagner *et al.* (2009)	**Proposed approach**
Objective	Describe transition stepping behaviours associated with manual material handling tasks; Use a compact notation to quantify the sequence of steps during object transitions (pickups or deliveries).	Describe strategies rather than footstep patterns; Provide an exhaustive classification of foot placement and movement strategies; Describe strategies according to key checkpoints throughout the handling task.
Limits	Lack of specificity for the move step class; No movement information given by the terminal stance state with regard to the task performed by the upper limbs; Assumes that the handler is facing the job while picking up the load; Do not inform about strategies at specific checkpoints throughout the handling task.	Describes footstep patterns with less precision, especially while transferring the load.

Table 2: Stances for positions of the feet at first contact, lifting, pre-deposit and deposit.

Position	Definition
Even stance {E}	Both feet pointing toward the pallet (Figure 2: left)

Contralateral foot forward {S}
Ipsilateral foot forward {R}
	• Contralateral {S} or ipsilateral {R} foot is positioned forward the other
	• Foot is considered behind if the toes of the back foot do not exceed the heel of the front foot
	• Front foot is pointing toward the pallet (< 45°)
	• Distinction between {I} and {C}
	    o Lifting: Front foot is ipsilateral {I}or contralateral {C} to the direction of the turning rotation towards deposit
	    o Deposit: Front foot is ipsilateral {I}or contralateral {C} to the direction of the return rotation

Parallel, ipsilateral {I}
Parallel, contralateral {C}
	• Feet are pointing in a parallel angle in relation to the pallet width line (Figure 2: right)
	• Distinction between {I} and {C}
	    o Lifting: Feet pointing in the direction of the rotation {I} or in the opposite direction {C}
	    o Deposit: Feet pointing in the direction of the return rotation {I} or in opposite direction {C}

Crossovers between stances	**Criteria**

	1. Rotation from the pallet (where front foot facing the pallet is at 0°) of the front foot (the one closest to the pallet)
	    o > 45°: Parallel stance
	    o < 45°: Check "Orientation of the trunk" criterion
	2. Orientation of the trunk
	    o Not facing the pallet: Parallel stance
	    o Facing the pallet: Check whether the toes of the back foot do not exceed the heel of the front foot, i.e. the second criterion for the Contralateral/ipsilateral foot forward is met
	        ▪ Yes: Contralateral/ipsilateral foot forward
	        ▪ No: Even stance

Table 3: Stances for movements of the feet at first contact, lifting, pre-deposit and deposit.

Movement codes	Definition
No movement {N-M}	Feet remain stationary or are in double support position (both touching the ground) during a walking cycle
Backward translation {B-T}	Handler takes one step away from the pallet
Forward translation{F-T}	Handler takes one step toward the pallet
Pivot of back foot {P}	Back foot changes orientation while staying stationary
Pivot & translation combination {P-T}	Handler takes a step while changing orientation of the ipsilateral foot
Counterweight {C}	One foot lifted backward, but no backward step

Table 4: Stances for movements of the feet during transfer.

Movement codes	Definition
No movement {N-M}	Feet do not move
Progressive turn {Pr}	• The handler takes at least 3 steps to turn around (180°) • Small turns are made at each step • The first foot to move is contralateral
Open turn {O}	• The handler takes 2 steps to turn around (180°) • The first foot to move is ipsilateral • Greater reorientation occurs at each step
Pivot {P}	• Turn is made in one step • The foot on which the handler applies his/her weight pivots during the turn
Crab {Cr}	• Handler does not completely turn toward the deposit pallet • Handler takes sideways steps to move from pickup to deposit pallet

Table 5: Intra- and inter-rater reliability, assessed using percentage of agreement, Cohen's kappa (k), PABAK and Gwet's AC1 (± 95% confidence interval bounds) for the four instants and the transfer phase of the MMH task.

		Intra-rater reliability				Inter-rater reliability			
Phase	**Stance**	**Agreement**	**K**	**PABAK**	**AC1**	**Agreement**	**K**	**PABAK**	**AC1**
First contact	**Position**	0.87	0.75	0.69	0.80	0.70	0.55	0.41	0.62
			(0.07)	(0.07)	(0.05)		(0.11)	(0.11)	(0.09)
	Movement	0.95	0.32	0.88	0.94	0.77	0.14	0.54	0.76
			(0.32)	(0.32)	(0.02)		(0.24)	(0.24)	(0.07)
Lifting	**Position**	0.92	0.83	0.79	0.87	0.82	0.69	0.63	0.77
			(0.08)	(0.08)	(0.04)		(0.12)	(0.12)	(0.07)
	Movement	0.80	0.65	0.61	0.78	0.80	0.69	0.61	0.78
			(0.09)	(0.09)	(0.04)		(0.11)	(0.11)	(0.07)
Transfer	**Movement**	0.87	0.69	0.72	0.86	0.74	0.35	0.49	0.71
			(0.17)	(0.17)	(0.06)		(0.18)	(0.18)	(0.08)
Pre-deposit	**Position**	0.84	0.62	0.55	0.72	0.71	0.50	0.42	0.60
			(0.08)	(0.08)	(0.05)		(0.13)	(0.13)	(0.10)
	Movement	0.99	0.00	0.98	0.99	0.52	0.01	0.05	0.47
			(0.98)	(0.98)	(0.01)		(0.15)	(0.15)	(0.09)
Deposit	**Position**	0.94	0.82	0.78	0.86	0.83	0.71	0.66	0.76
			(0.08)	(0.08)	(0.04)		(0.12)	(0.12)	(0.08)
	Movement	0.94	0.32	0.86	0.92	0.89	0.51	0.78	0.88
			(0.28)	(0.28)	(0.03)		(0.27)	(0.27)	(0.05)
Mean		0.90	0.55	0.76	0.86	0.75	0.46	0.51	0.71
Median		0.92	0.65	0.78	0.86	0.77	0.51	0.54	0.76
Max		0.99	0.83	0.98	0.99	0.89	0.71	0.78	0.88
Min		0.80	0.00	0.55	0.72	0.52	0.01	0.05	0.47

Table 6: Strategies (position and movement stances) for the four instants of the handling task.

Instant	Strategy	Code	Frequency (%)
First contact	Even stance–No movement	$E_{N\text{-}M}$	49
	Parallel, ipsilateral–No movement	$I_{N\text{-}M}$	28
	Contralateral foot forward–No movement	$S_{N\text{-}M}$	10
Lifting	Even stance–No movement	$E_{N\text{-}M}$	29
	Parallel, ipsilateral–No movement	$I_{N\text{-}M}$	16
	Parallel, ipsilateral–pivot & translation	$I_{P\text{-}T}$	15
Pre-deposit	Ipsilateral foot forward–No movement	$R_{N\text{-}M}$	30
	Contralateral foot forward–No movement	$S_{N\text{-}M}$	29
	Even stance–No movement	$E_{N\text{-}M}$	28
Deposit	Even stance–No movement	$E_{N\text{-}M}$	53
	Ipsilateral foot forward–No movement	$R_{N\text{-}M}$	19
	Contralateral foot forward–No movement	$S_{N\text{-}M}$	12

Table 7: Three most frequently used strategies for the three phases of the handling task and the transitions between the phases and the five most frequently used sequences.

Phase	Strategy	Code	Frequency (%)
Preparation	Even stance–No movement, Even stance–No movement	$E_{N\text{-}M}$, $E_{N\text{-}M}$	26
	Parallel, ipsilateral–No movement, Parallel, ipsilateral–No movement	$I_{N\text{-}M}$, $I_{N\text{-}M}$	12
	Even stance–No movement, Even stance–pivot-translation	$E_{N\text{-}M}$, $E_{P\text{-}T}$	12
Transition from lifting to transfer	Even stance–No movement, Progressive turn	$E_{N\text{-}M}$, T_{Pr}	18
	Parallel, ipsilateral–Pivot-translation, Open turn	$I_{P\text{-}T}$, T_O	15
	Parallel, ipsilateral–No movement, Open turn	$I_{N\text{-}M}$, T_O	14
Transfer	Open turn	T_O	73
	Progressive turn	T_{Pr}	22
	Crab	T_{Cr}	2
Transition from transfer to pre-deposit	Open turn, Ipsilateral foot forward–No movement	T_O, $R_{N\text{-}M}$	25
	Open turn, Contralateral foot forward–No movement	T_O, $S_{N\text{-}M}$	20
	Open turn, Even stance–No movement	T_O, $E_{N\text{-}M}$	20
Lowering	Even stance–No movement, Even stance–No movement	$E_{N\text{-}M}$, $E_{N\text{-}M}$	24
	Contralateral foot forward–No movement, Even stance–No movement	$S_{N\text{-}M}$, $E_{N\text{-}M}$	17
	Ipsilateral foot forward–No movement, Ipsilateral foot forward–No movement	$R_{N\text{-}M}$, $R_{N\text{-}M}$	16
Whole sequence	{$E_{N\text{-}M}$, $E_{N\text{-}M}$, Pr, $E_{N\text{-}M}$, $E_{N\text{-}M}$}		5
	{$E_{N\text{-}M}$, $E_{N\text{-}M}$, Pr, $S_{N\text{-}M}$, $E_{N\text{-}M}$}		5
	{$E_{N\text{-}M}$, $E_{P\text{-}T}$, O, $S_{N\text{-}M}$, $E_{N\text{-}M}$}		4
	{$E_{N\text{-}M}$, $E_{N\text{-}M}$, O, $E_{N\text{-}M}$, $E_{N\text{-}M}$}		3
	{$E_{N\text{-}M}$, $E_{P\text{-}T}$, O, $R_{N\text{-}M}$, $E_{N\text{-}M}$}		2

Table 8: Comparison of the Inter-rater reliability results between the current study with those from Wagner *et al.* (2009), assessed using percentage of agreement, Cohen's kappa (k), PABAK and Gwet's AC1 (± 95% confidence interval bounds) for the four instants and the transfer phase of the MMH task.

	Wagner *et al.* (2009)			Current study			
Variable	**Agreement**	**Kappa**	**Variable**	**Agreement**	**K**	**PABAK**	**AC1**
Step/turn direction	0.92	0.90	**Average position stance**	0.77	0.61	0.53	0.69
L-TRACS behavior (individual)	0.25	0.33	**Average movement stance**	0.75	0.34	0.50	0.72
L-TRACS behavior (grouped)	0.47	0.78	**Transfer**	0.74	0.35	0.49	0.71
Number of steps	0.68	0.56					
Terminal stance	0.56	0.54					

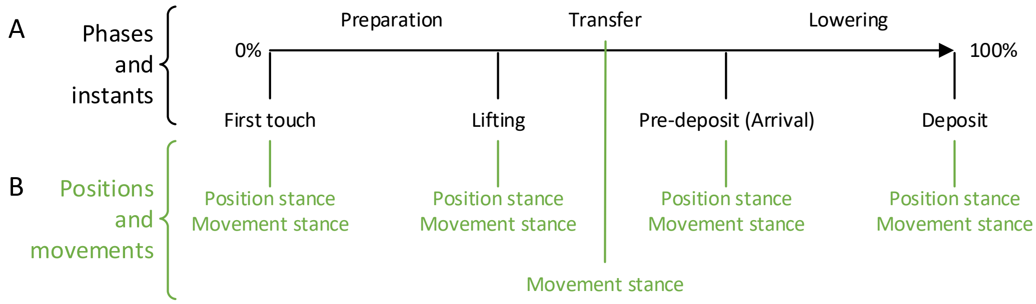
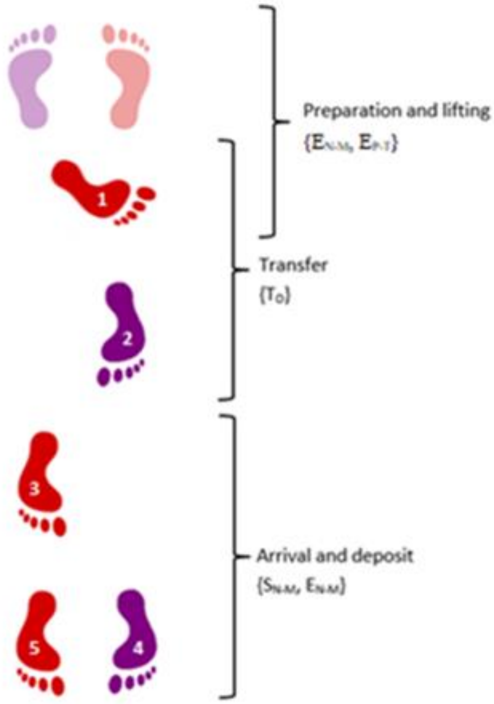


Figure 1: Phases and instants of a typical handling cycle (0%–100%) (A) and position and movement stances attributed to each instant and phase (B).

Figure 2 : Visual representations of the five position stances in relation to the lifting pallet: A) Even stance; B) Contralateral foot forward; C) Ipsilateral foot forward; D) Parallel (ipsilateral); E) Parallel (contralateral).

A



B

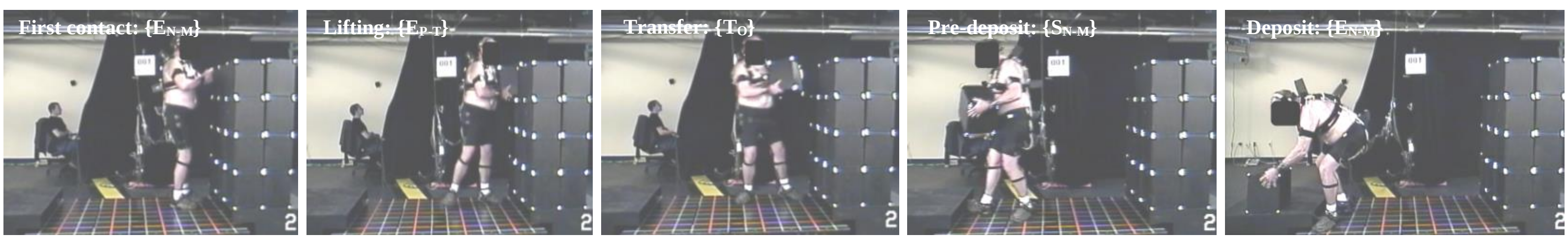
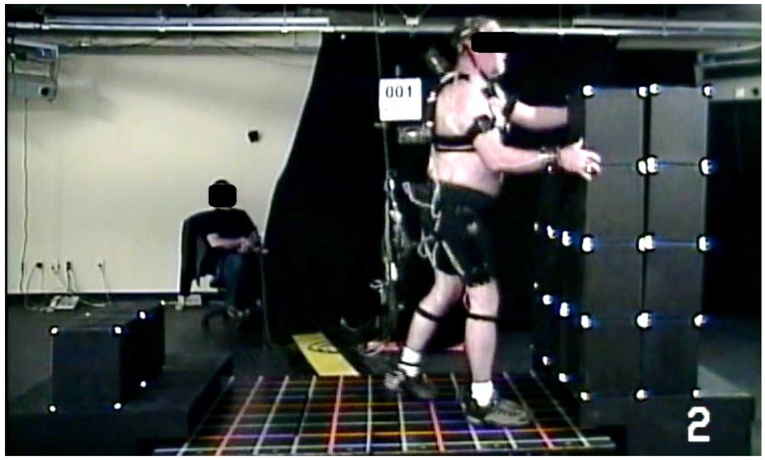
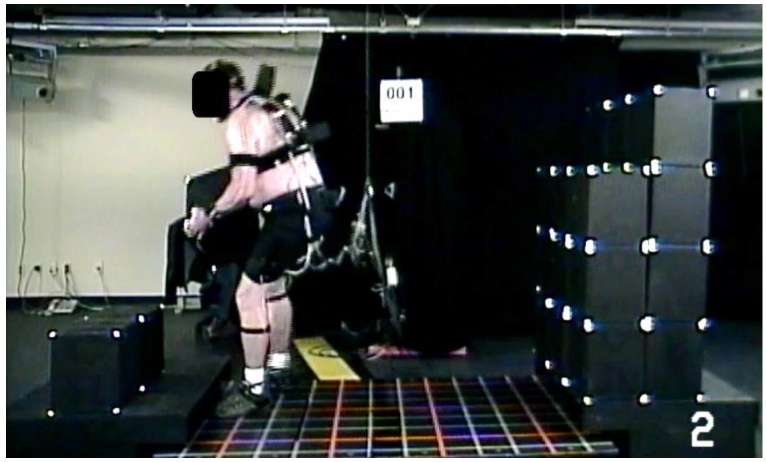
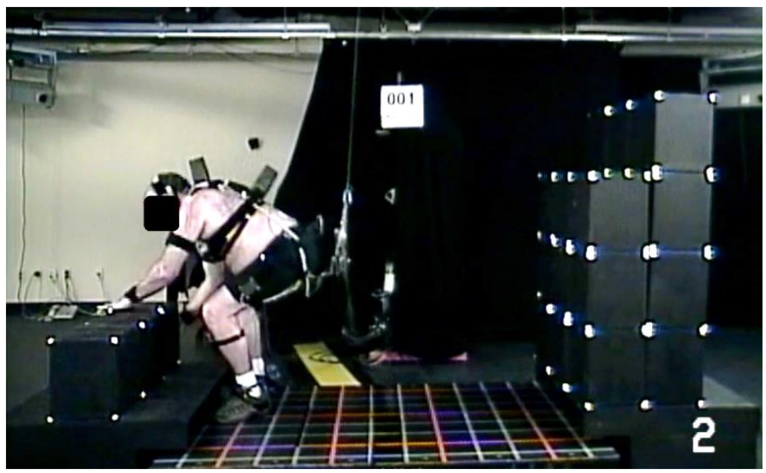


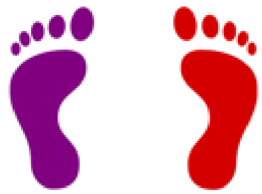
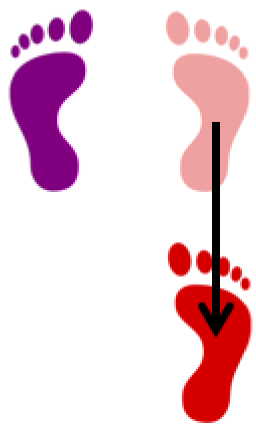
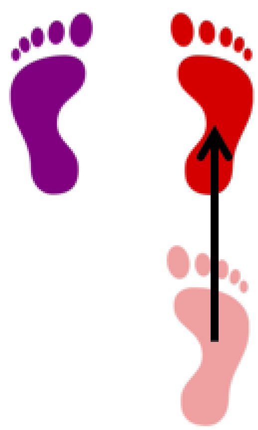
Figure 3: (A) Example of sequence: S = {E_{N-M}, E_{P-T}, T_O, S_{N-M}, E_{N-M}}, where the numbers indicate the order of each step. (B) Visual representation of the sequence.

Appendix 1: Visual representations of the four instants of the handling cycle.

Instant	Criteria	Picture
First contact	Hands touch the box	
Lifting	Box no longer in contact with the surface	

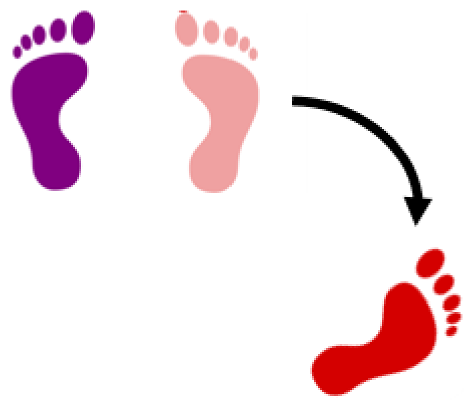
Pre-deposit	• One foot at the deposit location • Initiation of box depositing	
Deposit	Box touching the surface	

Appendix 2: Visual representations of the movements at the four instants of the handling cycle pictured with an {Even stance}.

Movement	Diagram
No movement {N-M}	
Backward translation {B-T}	
Forward translation{F-T}	

Pivot of back foot {P}

Pivot & translation combination {P-T}



Counterweight {C}

Appendix 3: Visual representations of the movements for the transfer phase.

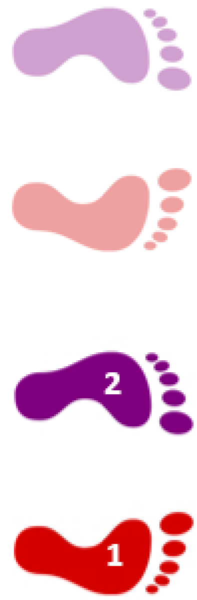
Movement	Diagram
No movement {N-M}	
Progressive turn {Pr}	

Open turn {O}

Pivot {P}

Dépôt institutionnel

Crab {Cr}



Supplementary material

Table 9: Confusion matrix between rater 1A and rater 1B for the assessment of intra-rater reliability of the classification of the position stances during the first contact, lifting, pre-deposit and deposit instants.

First contact							
				Rater 1A			
		{E}	**{S}**	**{R}**	**{I}**	**{C}**	**Total**
Rater 1B	**{E}**	186	8	0	6	0	**200**
	{S}	10	37	0	11	0	**58**
	{R}	4	0	32	0	2	**38**
	{I}	4	17	0	88	0	**109**
	{C}	0	3	0	0	6	**9**
	Total	**204**	**65**	**32**	**105**	**8**	**414**
Lifting							
				Rater 1A			
		{E}	**{S}**	**{R}**	**{I}**	**{C}**	**Total**
Rater 1B	**{E}**	196	4	0	4	0	**204**
	{S}	1	15	0	6	0	**22**
	{R}	0	0	27	0	1	**28**
	{I}	10	10	0	131	0	**151**
	{C}	0	2	0	5	2	**9**
	Total	**207**	**31**	**27**	**146**	**3**	**414**
Pre-deposit							
				Rater 1A			
		{E}	**{S}**	**{R}**	**{I}**	**{C}**	**Total**
Rater 1B	**{E}**	107	16	0	0	0	**122**
	{S}	34	77	0	1	0	**112**
	{R}	16	0	90	10	0	**117**
	{I}	0	13	0	46	0	**59**
	{C}	0	4	0	0	0	**4**
	Total	**157**	**110**	**90**	**57**	**0**	**414**
Deposit							
				Rater 1A			
		{E}	**{S}**	**{R}**	**{I}**	**{C}**	**Total**
Rater 1B	**{E}**	199	9	0	0	0	**208**
	{S}	4	48	0	0	0	**52**
	{R}	4	0	70	9	0	**83**
	{I}	0	15	0	52	0	**67**
	{C}	0	4	0	0	0	**4**
	Total	207	76	70	61	0	**414**

Table 2: Confusion matrix between rater 1 and rater 2 for the assessment of inter-rater reliability of the classification of the position stances during the first contact, lifting, pre-deposit and deposit instants.

		Rater 1					
First contact							
		{E}	**{S}**	**{R}**	**{I}**	**{C}**	**Total**
Rater 2	**{E}**	67	22	0	0	0	89
	{S}	1	22	0	0	0	23
	{R}	3	0	12	0	0	15
	{I}	6	20	0	25	0	51
	{C}	0	1	0	0	0	1
	Total	77	65	12	25	0	179
Lifting							
		Rater 1					
		{E}	**{S}**	**{R}**	**{I}**	**{C}**	**Total**
Rater 2	**{E}**	85	6	0	2	0	93
	{S}	1	8	0	3	0	12
	{R}	1	0	5	0	0	6
	{I}	7	12	0	47	0	66
	{C}	0	1	0	0	1	2
	Total	94	27	5	52	1	179
Pre-deposit							
		Rater 1					
		{E}	**{S}**	**{R}**	**{I}**	**{C}**	**Total**
Rater 2	**{E}**	38	31	0	0	0	69
	{S}	2	39	0	0	0	41
	{R}	4	0	38	0	0	42
	{I}	1	14	0	12	0	27
	{C}	0	0	0	0	0	0
	Total	45	84	38	12	0	179
Deposit							
		Rater 1					
		{E}	**{S}**	**{R}**	**{I}**	**{C}**	**Total**
Rater 2	**{E}**	88	7	0	0	0	95
	{S}	0	23	0	0	0	23
	{R}	8	0	25	0	0	33
	{I}	1	14	0	13	0	28
	{C}	0	0	0	0	0	0
	Total	97	44	25	13	0	179

Table 3: Confusion matrix between rater 1A and rater 1B for the assessment of intra-rater reliability of the classification of the movement stances during the first contact, lifting, pre-deposit and deposit instants.

First contact

		Rater 1A						
		{N-M}	{P-T}	{F-T}	{B-T}	{P}	{C}	Total
Rater 1B	{N-M}	384	0	6	0	6	7	**403**
	{P-T}	0	0	0	0	0	0	**0**
	{F-T}	3	0	0	0	0	0	**3**
	{P}	0	0	0	0	0	0	**0**
	{B-T}	0	0	0	0	0	0	**0**
	{C}	2	0	0	0	0	6	**8**
	Total	**389**	**0**	**6**	**0**	**6**	**13**	**414**

Lifting

		Rater 1A						
		{N-M}	{P-T}	{F-T}	{B-T}	{P}	{C}	Total
Rater 1B	{N-M}	213	17	1	1	8	0	**240**
	{P-T}	18	99	0	0	4	2	**123**
	{F-T}	1	1	2	0		0	**4**
	{P}	2	2	0	0	3	0	**7**
	{B-T}	14	7	0	0	19	0	**40**
	{C}	0	0	0	0	0	0	**0**
	Total	**248**	**126**	**3**	**1**	**34**	**2**	**414**

Pre-deposit

		Rater 1A						
		{N-M}	{P-T}	{F-T}	{B-T}	{P}	{C}	Total
Rater 1B	{N-M}	1	410	1	0	0	0	**412**
	{P-T}	0	0	0	0	0	0	**0**
	{F-T}	0	1	0	0	0	0	**1**
	{P}	0	0	0	0	0	0	**0**
	{B-T}	0	0	0	0	0	0	**0**
	{C}	0	1	0	0	0	0	**1**
	Total	**1**	**412**	**1**	**0**	**0**	**0**	**414**

Deposit

		Rater 1A						
		{N-M}	{P-T}	{F-T}	{B-T}	{P}	{C}	Total
Rater 1B	{N-M}	376	0	0	0	0	24	**400**
	{P-T}	0	0	0	0	0	0	**0**
	{F-T}	1	0	0	0	0	0	**1**
	{P}	0	0	0	0	0	0	**0**
	{B-T}	0	0	0	0	0	0	**0**
	{C}	5	0	0	0	0	8	**13**
	Total	**382**	**0**	**0**	**0**	**0**	**32**	**414**

Table 4: Confusion matrix between rater 1 and rater 2 for the assessment of inter-rater reliability of the classification of the movement stances during the first contact, lifting, pre-deposit and deposit instants.

First contact

		Rater 1						
		{N-M}	**{P-T}**	**{F-T}**	**{P}**	**{B-T}**	**{C}**	**Total**
Rater 2	**{N-M}**	134	1	23	1	7	8	**174**
	{P-T}	0	0	0	0	0	0	**0**
	{F-T}	0	0	0	0	0	0	**0**
	{P}	0	0	0	0	0	0	**0**
	{B-T}	0	0	0	0	0	0	**0**
	{C}	1	0	0	0	0	4	**5**
	Total	**135**	**1**	**23**	**1**	**7**	**12**	**179**

Lifting

		Rater 1						
		{N-M}	**{P-T}**	**{F-T}**	**{P}**	**{B-T}**	**{C}**	**Total**
Rater 2	**{N-M}**	79	2	0	0	6	1	**88**
	{P-T}	6	51	0	0	9	1	**67**
	{F-T}	0	0	0	0	1	0	**1**
	{P}	3	0	0	0	2	0	**5**
	{B-T}	0	2	0	0	16	0	**18**
	{C}	0	0	0	0	0	0	**0**
	Total	**88**	**55**	**0**	**0**	**34**	**2**	**179**

Pre-deposit

		Rater 1						
		{N-M}	**{P-T}**	**{F-T}**	**{P}**	**{B-T}**	**{C}**	**Total**
Rater 2	**{N-M}**	93	0	5	66	5	7	**176**
	{P-T}	0	0	0	0	0	0	**0**
	{F-T}	0	0	0	0	0	0	**0**
	{P}	0	0	0	0	0	0	**0**
	{B-T}	0	0	0	0	0	0	**0**
	{C}	2	0	0	0	0	1	**3**
	Total	**95**	**0**	**5**	**66**	**5**	**8**	**179**

Deposit

		Rater 1						
		{N-M}	**{P-T}**	**{F-T}**	**{P}**	**{B-T}**	**{C}**	**Total**
Rater 2	**{N-M}**	147	0	0	8	2	6	**163**
	{P-T}	0	0	0	0	0	0	**0**
	{F-T}	0	0	0	0	0	0	**0**
	{P}	0	0	0	0	0	0	**0**
	{B-T}	0	0	0	0	0	0	**0**
	{C}	3	0	1	0	0	12	**16**
	Total	**150**	**0**	**1**	**8**	**2**	**18**	**179**

Table 5: Confusion matrix between rater 1A and rater 1B for the assessment of intra-rater reliability of the classification of the movement stances during the transfer.

		Rater 1A						
		{Pr}	**{O}**	**{Cr}**	**{I}**	**{P}**	**{N-M}**	**Total**
Rater 1B	**{Pr}**	40	4	0	0	0	0	**44**
	{O}	9	101	0	0	0	0	**110**
	{Cr}	0	4	1	1	0	0	**6**
	{I}	0	0	0	0	0	0	**0**
	{P}	0	2	0	0	0	0	**2**
	{N-M}	0	0	0	0	0	0	**0**
	Total	**49**	**111**	**1**	**1**	**0**	**0**	**162**

Table 6: Confusion matrix between rater 1 and rater 2 for the assessment of inter-rater reliability of the classification of the movement stances during the transfer.

		Rater 1						
		{Pr}	**{O}**	**{Cr}**	**{I}**	**{P}**	**{N-M}**	**Total**
Rater 2	**{Pr}**	13	24	0	0	0	0	**37**
	{O}	4	114	3	0	11	0	**132**
	{Cr}	0	2	1	0	0	0	**3**
	{I}	0	0	0	0	0	0	**0**
	{P}	1	0	0	0	6	0	**7**
	{N-M}	0	0	0	0	0	0	**0**
	Total	**18**	**140**	**4**	**0**	**17**	**0**	**179**