DO MONKEYS FIDGET? USING MOVEMENT ANALYSIS TO UNDERSTAND THE ROLE OF GAZE DIRECTION ON NON-INSTRUMENTAL OBJECT MANIPULATION: STONE HANDLING IN BALINESE LONG-TAILED MACAQUES

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ABSTRACT

Stone handling (SH) is a form of playful and repetitive object-directed manipulation performed by some non-human primates. SH includes approximately 40 behavioural patterns using the hands, feet, and mouth. Within a SH pattern, there are subtle variations in the manner they are performed (e.g., less rigid appearance). Currently, the psychological mechanisms underlying the performance of SH are poorly understood. This thesis aimed to examine the performance variations and subsequent structural variations in two SH patterns performed by Balinese long-tailed macaques: rubbing a stone on the ground and pounding a stone on the ground. Movement analyses revealed, for each SH pattern, two distinct variations correlated with gaze direction. The implications of these results were explored using information about fidgeting to hypothesize about potential relationships between SH, object play, and fidgeting.

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Chapter One

Introduction

"Ludic behaviour forms such a motley assortment that it is highly unlikely that all of it has just one function…so far it is mainly our ignorance that binds them all together." – Berlyne (1960, p. 5)

Stone handling (hereafter SH) is form of socially learned, culturally maintained, and playfully motivated object manipulation performed by several species of non-human primates (Cangiano & Palagi, 2020; Huffman, 1984; Huffman et al., 2008; Leca et al., 2007a, 2007b). SH is defined as the non-instrumental and playful manipulation of stones; there are approximately 40 distinct behaviour patterns, such as gathering stones into a pile, clacking two stones together, pounding a stone onto another stone, rubbing a stone on the ground, inserting/dropping small stones into cavities (Pelletier et al., 2017). The way an individual manipulates the stone(s) may vary based on their age, individual preference, environmental context (e.g., food provisioning), and object constraints (e.g., stone affordances) (Cenni et al., in review; Leca et al., 2008a, 2008b, 2010a, 2010b; Nahallage & Huffman, 2008a). For example, a given individual may choose to primarily use both hands when rolling a stone, whereas another individual may choose to primarily use one hand.

After viewing the Balinese long-tailed macaques engage in SH at the Sacred Monkey Forest in Ubud, Bali Indonesia, I noticed that the behaviour appears similar to the repetitive, often object-directed, behavioural category performed by humans – fidgeting (Perrykkad & Hohwy, 2020). I observed instances in which an individual seemed to be very concentrated and engaged in performing a SH pattern (i.e., focused on the SH actions while ignoring environmental distractions), but if there was an agonistic interaction in the distance, the same individual appeared to be distracted and engage in a less vigorous version of the same SH Pattern (Chertoff, personal observation; for a review on concentration, see Moran, 2012). Previous research on SH has not identified the role of attention in the performance of this behaviour. The problem is that beyond anecdotal accounts of individuals being "seemingly distracted" while engaging in SH, we do not know whether the individuals are physically fatigued, momentarily distracted, or even possibly experiencing a state of mind-wandering while engaging in SH. Thus, there might be attention-related variations in the performance of SH (i.e., putative differences in levels of concentration associated with subtle variation in the expression of SH behaviour). To further understand the proximate and ultimate cause(s) of SH, this thesis aims to provide a description of the kinematic and non-kinematic components of two SH patterns that may then be used in comparative and hypothesis-driven studies.

Tinbergen (1963) argued that the first step of studying a behaviour is to describe the structural components and distinguishing traits of the behaviour. This approach is useful when attempting to identify behaviours, their cause(s) (i.e., proximate mechanisms), and their function(s) (i.e., ultimate utilities). According to the structure-to-function framework and the "design-feature argument," the structural analysis of a behaviour pattern provides information about its hypothesized function (Cenni et al., 2020; Martin & Caro, 1985; Moran, 1985). The heuristic power of the behavioural structure-function interface is reflected in the following statement by Pellis and Pellis (1998), "Therefore, behavioral description informs functional inference, which in turn, influences further description" (p. 115). Subtle differences in the structural organization of evolutionary related behaviours are indicative of their respective motivational underpinnings and functional features. This approach has proved particularly useful to compare playful and instrumental forms of object manipulation (Hughes, 1978, 1979; Pelletier et al., 2017; Pellis et al., 2019). It uses structural variables, either based on kinematic, non-kinematic, or temporal components, to infer underlying psychological mechanisms and explain the actions being performed in terms of proximate or ultimate utility. The kinematic components of a behaviour involve how the organism is moving, including when and how they move their limbs relative to their own body, objects, other organisms, and the space around them (Bartenieff & Lewis, 1980; Foroud & Pellis, 2003; Foroud & Whishaw, 2006). The non-kinematic qualities of a behaviour often involve the exertion of energy throughout the movement and usually either support or hinder the performance of the kinematic components of the action(s) (Foroud & Whishaw, 2006).

In response to Smith's (1982) article outlining the potential functions of play, Moran (1985) expressed concern regarding "…the ease with which we, as humans, are able to agree upon what is playful on an impressionistic basis" (p.187). He criticized a "top-down" approach that consists of first pre-defining a behaviour as playful on the basis of its hypothesized function and then trying to match the requirements of this purported function against the observed structure of the behaviour. Instead, he argued that a "bottom-up approach" that relies on the description of the structure of a behaviour without reference to any functional categorization allows researchers to identify patterns across age and sex classes, groups, populations, and species. According to Martin and Caro (1985), "…the implication is that beneficial effects of major importance, and for which play has the appropriate structural characteristics or "design features," are likely to constitute its functions" (p. 60). Simply put, if a behaviour, such as play, has a specific function, its structure should reflect this function.

Researchers use the behavioural structure-function interface to explore the cognitive underpinnings (e.g., attentional states, motivational processes) of otherwise elusive behavioural categories, such as object play (Hughes, 1978; Hughes 1979; Hutt 1966; Hutt, 1997; Pelletier et al., 2017; Pellis et al., 2019). Hughes (1978, 1979) conducted a sequential structural analysis of object manipulation, in which she quantified the similarities and differences of the temporal structure of object exploration and object play. Building on Hutt's (1966, 1967) studies in which she identified the different behavioural responses to a novel toy, Hughes (1978, 1979) confirmed that exploratory behaviour is more functionally constrained and less structurally variable than play behaviour. Even though the individual movements looked very similar, during exploration, children typically engaged in behaviours within one behavioural cluster (e.g., touch is one cluster as would be visual inspection) whereas during play children switched between clusters (e.g., walk, touch, gesture). Hughes reinforced Hutt's (1966, 1947) prediction and findings that exploration is more constrained (due to functional implications) than play. As stated by Hutt (1966), exploration is the process in which an individual learns "what does this *object* do?" (p.76) while play is the process in which an individual learns "what can *I* do with this object?" (p. 76). Both Hughes' and Hutt's work have demonstrated the strength of structural analysis when studying two seemingly similar behaviours that otherwise are difficult to distinguish.

The structure-to-function framework has proven invaluable in previous studies of rituals, stereotypy, and compulsive behaviour (Eilam et al., 2006; Eilam et al., 2012;

Eilam, 2015). Using a sequential analysis, Eilam et al. (2012) analysed how individuals with obsessive compulsive disorder (OCD) and control individuals performed a task, such as "preparing a meal." The authors found that the control individuals primarily performed the functional movements (e.g., putting the plate on the table) of the task whereas individuals with OCD performed functional and non-functional movements (e.g., repeatedly moving the chair in the room). Non-functional movements were unique acts deemed unnecessary or irrelevant to the on-going task (Zor et al., 2009). Eilam et al. (2012) found that, compared to control participants, patients with OCD performed the task with higher frequencies of repetition as well as higher frequencies of idiosyncratic movements. As stated by Eilam et al. (2012), the use of a structural, video-based analysis eliminates some of the subjectivity associated with self-reports when diagnosing patients.

The structure-to-function framework is not limited to human-based studies; it has also been applied to behavioural research in insects, birds, and mammals (Fagan et al., 1997; Foroud & Pellis, 2003; Pellis et al., 2013; for review, see Pellis and Pellis, 1998). For example, Foroud and Pellis (2003) used a movement analysis system, Laban Movement Analysis (LMA) to study the body movements of juvenile and adult rats engaged in social rough and tumble play (RTP) behaviour. LMA is a unique movement analysis system in that it includes both the kinematic and non-kinematic properties of a behavioural sequence to provide a holistic view of the behaviour (Bartenieff & Lewis, 1980; Foroud & Whishaw, 2006). Using LMA, the authors determined that during RTP, juvenile rats use more "gentle" Effort Qualities (i.e., a non-kinematic property of movement) than adult rats (p.40) and position themselves in ways that make them more vulnerable to their play partners than the way adult rats position themselves. Specifically, the data presented by Foroud and Pellis (2003) demonstrated that the risky positions juveniles put themselves into leads to a loss of balance and in doing so, changes the dynamic of the playful interactions thus creating more opportunity for role-reversals (reciprocity) during RTP. These results lend themselves to the hypothesis that early motor experiences aid in the development of decision-making processes during adult social encounters. The use of LMA in this study has provided objective results that have broadened the standard hypotheses of social play, thereby opening the door to potentially new hypotheses surrounding play behaviour in juvenile and adult non-human animals.

Within the realm of SH, the use of another movement analysis system has proven valuable. Pelletier (2017) used Eshkol-Wachmann Movement Notation (EWMN) to study the motivational processes underlying the performance of SH in Balinese long-tailed macaques (*Macaca fascicularis*). Since juveniles engage in play more frequently than adults, researchers have questioned whether the exaggerated and not fully functional movements (compared to their functional counterparts) of play behaviour are due to an underdeveloped sensorimotor coordination (Burghardt, 2005; for a review of play behaviour see Pellis & Pellis, 2021)**.** Pelletier (2017) measured a series of parameters of the actions associated with the pounding of edible objects (i.e., nuts) by adult males, and the pounding of non-edible objects (i.e., stones) by juvenile and adult males. Nut pounding provided a template for a functional percussive action, motivated by foraging, whereas stone pounding provided a template for a seemingly functionless, and distinctly motivated playful action. Using EWMN, the author found that stone pounding in both juveniles and adults was similar in the duration, strike speed, stone height, and gaze direction of the pound. These data primarily support the hypothesis that juvenile and adult macaques manipulate the stones in a similar, playful manner. Additionally, the author found that the movements composing nut pounding were more constrained than stone pounding, likely due to the functional motivation of nut pounding. These results provide valuable insight into the motivational properties of SH (see also, Pellis et al., 2019). They also demonstrate the explanatory power of using a fine-grained structural analysis when studying repetitive and phenotypically similar behaviours. The following section will describe the current state of knowledge surrounding SH.

STONE HANDLING

SH is a category of non-instrumental, playful, stone-directed manipulative behaviour performed by geladas (*Theropithecus gelada*), Japanese macaques (*Macaca fuscata*), rhesus macaques (*M. mulatta*), Taiwanese macaques (*M. cyclopis*), and long-tailed macaques (Cangiano & Palagi, 2020; Nahallage et al., 2016; Pelletier et al., 2017). Within populations of macaques whose individuals engage in SH, there are approximately 40 distinct SH (behaviour) patterns (Cenni et al., in press; Huffman, 1984; Leca et al., 2007a; Nahallage & Huffman, 2012; Pelletier et al., 2017). The high amounts of inter- and intra- individual variability associated with SH may stem from the cultural diffusion of SH (Huffman et al., 2008; Leca et al., 2007a, 2007b).

Within the free-ranging group of Japanese macaques living at Arashiyama, Kyoto, three phases of the cultural diffusion of SH have been documented (Huffman, 1984; Huffman & Quiatt, 1986). During the transmission phase, SH first spread from the innovator (i.e., a young female individual) to her peers and siblings. Second, once (some of) these (female) individuals matured and reproduced, their infants observed them performing SH and began to engage in SH themselves: this is the tradition phase. Third, during the transformation phase, a variety of new SH patterns emerged through the acquisition and possible modification of SH patterns over time and across generations of monkeys. Although the cultural diffusion of SH has only been explicitly documented in one group of Japanese macaques, it is presumed that the presence of SH in additional populations and species of macaques is due to cultural diffusion (Huffman et al., 2008; Nahallage & Huffman, 2008b).

Furthermore, most SH sequences have a repetitive component. A SH bout is typically defined as a period of time in which an individual performs a SH sequence consisting of the repetition of one or multiple SH patterns with breaks no longer than 120 seconds (Huffman, 1996). Each individual repetition of a SH pattern, for example one pound or one rub within a SH sequence, may also vary in their presentation with some repetitions being kinematically similar or dissimilar (Pelletier, 2017). Additionally, the SH patterns are arbitrary in that there does not appear to be any specific criteria for the choice of SH patterns performed within a given SH sequence (Cenni et al., in review; Pelletier et al., 2017). Studies that have examined SH within the context of object play have contributed to our knowledge of motor development and tool use (Leca et al., 2008c, Nahallage et al., 2016; Pelletier, 2017; Pelletier et al., 2017).

SH has been hypothesized to be a precursor to tool use (Huffman & Quiatt, 1986; Leca et al., 2008c; Leca et al., 2012; Pelletier et al., 2017). Because SH occurs in food-provisioned populations, the members of those populations have more "free time" than their wild counterparts during which they can explore the properties of the stones (Huffman & Quiatt, 1986; cf. Beck, 1980). The exploration of stone affordances via the manipulation of these objects in a playful context may contribute to the acquisition of stone tool use in macaques (Tan, 2017). However, most macaque populations in which SH is an established behavioural tradition do not routinely engage in stone tool use, at least in a foraging context (but see Cenni et al., 2020; Leca et al., 2008c for stone tool use in non-foraging contexts); and in the macaque populations that routinely engage in stone tool-assisted foraging, SH has not been reported. Therefore, at this stage, the developmental and evolutionary connections between SH and stone tool use are only grounded in the "Affordance Learning" theory, and they remain largely hypothetical. Additionally, the exploration and manipulation of stones may promote motor skill development in young macaques and aid in the maintenance of neural functioning in aging macaques (Nahallage et al., 2016). Japanese macaque infants begin to perform SH at approximately six weeks of age and continue to perform this behaviour throughout their life (Nahallage & Huffman, 2007). As they develop, individuals continue to engage in SH in a more complex manner. Both the promotion of motor skill development and maintenance of neural functioning are presumed benefits of SH (Nahallage et al., 2016).

OBJECTIVES OF THIS THESIS

This thesis aims to further understand SH through descriptive structural analyses of seemingly rough/rigid performances and gentle/fluid performances of two SH patterns, rubbing a stone on the ground (hereafter "(stone) rubbing") and pounding a stone on the ground (hereafter "(stone) pounding"). Chapter Two of my thesis will focus on providing an in-depth explanation of LMA as well as presenting the methodology and resulting rating scales developed using LMA. Additionally, in Chapter Two, the rating scales are used to compare the kinematic and non-kinematic structure of rougher/rigid and gentler/fluid performances of the rubbing and pounding SH patterns. Findings from the movement analysis show orientating, the way the animal positions itself relative to the stone, to be a main difference between the rougher/rigid and gentler/fluid performance and led to the examination of SH in two different states of gaze direction: looking at the stone and not looking at the stone, described in Chapter Three. Chapter Four is a summary and discussion of the overall significance of this thesis as well as the limitations of, and future directions for this research project. Using EWMN and LMA, this thesis capitalizes on the objective measurements (i.e., EWMN and LMA do not depend on the researcher's pre-conceived notions of a behaviour) and fine-grained analysis afforded by movement analysis systems to explore the differences in the structure of stone rubbing and stone pounding when performed in a rougher/rigid manner and gentler/fluid manner, and in two different states of gaze direction: looking at the stone and not looking at the stone.

CHAPTER TWO

A Laban Movement Analysis of Stone Rubbing and Stone Pounding in Balinese Long-Tailed Macaques: Comparing Structural Variations within a Stone Handling Behaviour Pattern

Abstract

Stone handling (SH) is a form of non-instrumental object-directed manipulation, performed by geladas and multiple species of macaques. There are approximately 40 distinct SH behaviour patterns, such as rubbing and pounding. While handling stones, an individual may perform any number of distinct SH behaviour patterns (hereafter SH patterns) or repeatedly perform the same pattern using their hands, feet, and mouth. Within a single SH pattern (e.g., rubbing), the tension and overall intensity of performance may vary depending on the individual and environmental factors. This study used a fine-grained analysis, Laban Movement Analysis (LMA), to study the movement composition of two SH patterns, rubbing and pounding. Using LMA, two presentations of the same SH pattern, that appear to differ in movement quality, one seemingly rougher than the other, were notated for each SH pattern: rubbing and pounding. The movement analysis described the structural organization and qualitative aspects of the temporal sequence of movements of rubbing and pounding when performed in a rougher/rigid manner and a gentler/fluid manner. Two rating scales, one for rubbing and one for pounding, were compiled based on the descriptions from the movement analysis. Both rating scales were used in a small sample of subjects. Results from the rating scales suggest the way subjects orient their posture in relation to the stone differs between the two performance styles (rough versus gentler) in each of the SH patterns. The two rating

scales of the rubbing and pounding SH patterns may be used in future studies, such as to evaluate the role of orientation in SH.

Introduction

Stone handling (SH) is the culturally transmitted, playful, non-instrumental manipulation of stones performed by geladas (*Theropithecus gelada*)*,* Japanese macaques (*Macaca fuscata*), rhesus macaques (*M. mulatta*)*,* Taiwanese macaques (*M. cyclopis*)*,* and long-tailed macaques (*M. fascicularis*) (Cangiano & Palagi, 2020; Nahallage et al., 2016; Pelletier et al., 2017). SH consists of multiple behavioural patterns, referred to as SH patterns. A SH pattern is defined as a "single, non-instrumental, stone-directed, specifically defined manipulative action" (Pelletier, 2017, p. 26). The choice of SH pattern performed appears to be arbitrary in that there is no apparent specific reason as to why an individual would choose one SH pattern over another (e.g., an individual may choose to rub a stone rather than roll the stone) (Cenni et al., in review; Pelletier et al., 2017). SH patterns may be performed by the hands, feet, and mouth; again, the individual may choose to use one hand and a foot, whereas another individual may choose to use both hands (Leca et al., 2010a). Within a SH bout (i.e., a period of time in which an individual engages in SH with breaks no longer than 120 seconds), an individual may choose to perform a single pattern repeatedly, a combination of patterns, and use different limbs throughout the bout (cf. Huffman, 1996). To summarize, there are high amounts of intra- and inter-individual variability in the frequency of SH, SH pattern selection, and body parts used to execute the SH pattern. (Leca et al., 2010a; Pelletier, 2017; Pelletier et al., 2017).

When we have a detailed description of a behavioural expression, we are better able to recognize the behavioural expression across contexts (e.g., agonistic interactions vs. foraging). As previously stated, there are high amounts of structural variability in SH as a behavioural category. For example, there are 38 distinct SH patterns performed by Balinese long-tailed macaques, including cuddle, dislodge, rub together, pick and drop, and roll (Cenni et al., in press; Pelletier et al., 2017). SH patterns are performed across all age and sex classes leading to multiple presentations of the same pattern (Pelletier, 2017). Furthermore, SH patterns may have functional counterparts, such as the pounding SH pattern and the foraging-motivated and ultimately functional pounding of a nut on the ground to crack it open and eat the kernel (Pelletier, 2017; Pellis et al., 2019). Traditionally both performances would be categorized as pounding, but it is likely that the variations in performance are due to differing underlying cognitive mechanisms such as two different motivational states (e.g., a play motivational state versus foraging). The use of methods such as movement analysis, have improved our understanding of the structural components that make up a behavioural expression, and the causes (proximate or ultimate) of the behavioural expression (Foroud & Pellis, 2021; Golani, 1992).

Generally, variation in the occurrence of a behaviour may be the result of different underlying mechanisms (cf. Palvani et al., 1991). For example, Duboscq and colleagues (2016) used an information-theory framework to investigate the potential causes of scratching in female Japanese macaques. These researchers found that the occurrences of scratching were primarily due to parasites and social factors (e.g., agonistic interactions). This study exemplifies that one behaviour can occur because of multiple underlying cognitive mechanisms and ecological factors. While the researchers did not include a structural analysis of the scratching behaviour, their study highlights the importance of recognizing different causes of the same behaviour. Other researchers, such as Rutherford et al. (2012), have used qualitative methods to describe the body language of pigs in two environmental conditions (open field and elevated plus maze) either under the influence of a sedative or not. The observers identified the differing affective states associated with the pigs' behaviour in the two environmental conditions. The combination of evaluating the various contexts in which a behaviour may occur and describing the behaviour (i.e., the structure of the behaviour) can lead to a deeper understanding of the proximate and ultimate causes of the behaviour (Foroud & Pellis, 2021; Golani, 1992; Martin & Caro, 1985; Moran, 1985; Pellis & Pellis, 1998; Tinbergen, 1963).

As with most behavioural research, there is often a disconnect between what the observer has known to be the typical presentation of a behavioural expression and observing an atypical presentation of the behavioural expression. For example, maybe it is *how* (i.e., the structure) a subject reached across their face to scratch that just did not look the same as the ten other occurrences of scratching. This disconnect is difficult to identify and even more perplexing to objectively measure (cf. Fentress, 1992). A behavioural expression, such as scratching, can be broken down into multiple parts, such as the individual fine motor movements (e.g., the fingers bending), or gross motor movements (e.g., the entire arm moves up and down). Depending on how the researcher decides to parse the behavioural expression, it can appear as a typical or atypical presentation (Fentress, 1992, 2009). For example, if the observer is focused on gross motor movements and the subject uses their whole arm to scratch their face, the behaviour may look the same across contexts. However, if the observer is focused on fine motor movements during the scratch, they may notice that the subject is alternating moving their two fingers up and down on their face. The differences between the fine and gross motor movements may lead the observer to label the behavioural expressions as two different presentations, or even variations, of the behavioural expression. Describing a behaviour is the first step; however, without placing the behaviour in the context, we limit our understanding of the underlying mechanisms of the behaviour (Fentress, 1992).

The problem, within the behavioural category of SH, is that the potential variations seen in the execution of different SH patterns (i.e., variations of the structure of the behaviour) may be due to individual differences or style (e.g., handedness), different internal states (e.g., hunger), or object constraints (e.g., stone affordances) (Cenni et al., in-press; Leca et al., 2008a, 2008b, 2010a, 2010b; Nahallage & Huffman, 2008a). Previous research has used a behaviour systems approach to understand the motivations of different SH patterns (Pelletier et al., 2017; Pellis et al., 2019). In doing so, researchers hypothesized that most SH patterns performed by Balinese long-tailed macaques stem from a behaviour system grounded in foraging motivation.

Little is known about the quality of performance of SH patterns. For example, sometimes the macaques look like they are performing a SH pattern in a rough or rigid way and other times they look like they are performing the same SH pattern in a gentle or fluid way (Chertoff, personal observation). The difference in these performances, rough/rigid versus gentle/fluid, may reflect the inner state of the performer (Bartenieff & Lewis, 1980). It remains unknown whether this potential difference in the performance of a SH pattern is meaningful to the performer. Is the more rigid and rough performance due to stress? Is the gentle performance due to physical fatigue or loss of interest in the stones or the SH activity? If the difference is meaningful to the performer, then lumping the two types of performances of a SH pattern is problematic when attempting to identify the underlying mechanisms of SH as a behavioural category. If all instances of a SH pattern, such as rubbing, are grouped together even when one performance of rubbing may appear different (e.g., rigid/rough) than another (e.g., fluid/gentle), then lumping the rough and gentle performances of SH as one behavioural category may lead to the loss of information about the motivational underpinnings and functional features of the behaviour. Fentress (2008), a behavioural neuroscientist, clearly stated such a potential problem of disconnect in the following quote:

> "Clarity in observation is the first challenge. What do we look for, and what do we ignore […] What is a piece of a behaviour? We label actions in terms of nouns, but even that linguistic necessity can place a freeze frame on patterns of expression that in reality are much more fluid." (p. 6).

This chapter will continue to add to our knowledge of SH in Balinese long-tailed macaques by parsing the behavioural category even further into the kinematic (i.e., spatial-temporal, body and environmental relationship(s)) and non-kinematic (i.e., intensity, force, flow and rhythm) structure (Foroud & Pellis, 2003; Foroud & Whishaw, 2006) of two SH patterns, rubbing and pounding, performed in a neutral context, void of displacement behaviours and agonistic interactions (cf. Maestripieri et al., 1992; Troisi, 2002).). Previous studies have addressed a similar problem to the one presented in this chapter. For example, Foroud & Pellis (2003) used Laban Movement Analysis (LMA) to describe pinning, a play fighting behaviour, in adult and juvenile rats. The authors found that there were differences in the movement patterns between juvenile and adult rats, within the pinning behaviour, that previously were unidentified. From these findings, the authors were able to hypothesize about why the movement patterns differed. The use of

LMA in this study broadened the standard hypotheses of social play in juvenile and adult non-human animals.

Furthermore, Foroud and Whishaw (2006) used movement analysis to effectively identify, quantify, and analyse, structural differences in a reach-for-food task in human participants who had been affected by a stroke. The study demonstrated structural differences involving non-functional movements in the way participants recovering from stroke performed the task when compared with performance of the same task in healthy, age and sex matched control, participants. Non-functional movements tend to hinder the subjects' ability to reach-for-food. For example, the high amounts of tension in the limb (i.e., a non-functional component of a movement) can interfere with the limbs' smooth trajectory. These findings were developed into a rating scale which could then be applied by other researchers to aid in identifying subtle, descriptive differences in the structure of the behaviour that have implications for rehabilitation, chronic injury from compensatory movements, and fatigue expressed by patients which may otherwise have been glossed over. Identifying these subtle differences aids in both the diagnostic and treatment process for those who have suffered from a stroke(s).

Other researchers, such as Zor et al. (2009) have used video recordings of rituals (rituals were defined by the participants and thus were specific to each subject), such as filling up a water bowl for their pet, performed by subjects with and without obsessive-compulsive disorder (OCD), to identify structural differences in the performance of the rituals. Rituals were composed of multiple "acts" which were identified and then scored by reviewing the videos (e.g., in the water bowl ritual, "shake bowl" was considered an act) (p. 290). The researchers scored multiple videos of the subjects with and without

OCD performing the same rituals and found that rituals performed by subjects with OCD contained multiple non-functional acts (e.g., wave hands). This is an aspect of OCD rituals that previously had not been highlighted in the diagnostic criteria.

The present study uses LMA to describe both rigid/rough and fluid/gentle performances of two SH patterns performed by Balinese long-tailed macaques: rubbing and pounding. LMA is a language system for describing what the body does and how it is doing it (Bartenieff & Lewis, 1980; Foroud & Pellis, 2003; Foroud & Whishaw, 2006). Specifically, LMA describes how the multiple movement components interact within a movement sequence over time: what (e.g., body parts, the whole body, multiple individuals and their relative interactions), where (e.g., spatial dynamics and contexts), and how (e.g., non-kinematic movement dynamics such as rhythm). LMA allows for an objective description of a behaviour rather than relying solely on the subjective perception of the observer to identify differences in the performance of a behaviour.

Rubbing and pounding SH patterns were selected for this study because they are easily recognizable amongst the 36 other SH patterns. The rubbing and pounding SH patterns seem to occur frequently, although analyses to determine their frequency in the data base were not conducted. Additionally, rubbing and pounding are performed in two different spatial planes (horizontal and vertical respectively) providing two different movement spatial organization patterns to further describe. Finally, previous research using movement analysis has highlighted the pounding SH pattern, identifying phases of movement within a single pound (i.e., the upswing, adjustment and downswing) as well as the structural differences between nut pounding and stone pounding (Pelletier, 2017).

The purpose of the present study is to provide a detailed description of the movement components of two distinct SH patterns, rubbing and pounding, to help identify what makes some performances of the SH patterns appear rougher than others or gentler than others. Additionally, this study aims to identify whether the rougher performances and gentler performances are distinct variations of a SH pattern with differing movement qualities that contribute to the rougher/rigid or gentler/fluid appearance of the performance. These movement descriptions can then be used in future analyses to draw structural comparisons across motivational, attentional, and emotional contexts. More specifically, this chapter highlights the study of the spatial-temporal limb relationships, limb to body relationships, and environmental relationships, as well as the intensity, force, flow, and rhythm of rubbing and pounding performed by Balinese long-tailed macaques (for a review of kinematic vs. non-kinematic components, see Foroud & Pellis 2003; Foroud & Whishaw, 2006).

Methods

Study site and population

Data for this study were collected at the Sacred Monkey Forest in Ubud, Bali, Indonesia. The Sacred Monkey Forest, or Ubud Monkey Forest, is a central location for a population of free-ranging and urban dwelling Balinese long-tailed macaques *(Macaca fascicularis fascicularis)*. Due to high volume of tourists and staff, the long-tailed macaques are habituated to human presence. The population studied consisted of approximately 900 individuals in six different groups with overlapping home ranges (Cambier, 2019). The monkeys were provisioned with fruits and vegetables at least three times a day by the staff of the Ubud Monkey Forest.

Data collection and study subjects

Video-recorded observations were collected between May and August in 2016, 2018, and 2019 by members of the Leca Lab. Data were collected using focal sampling and *ad libitum* sampling methods (Altmann, 1974). In this study, I sampled 21 individually identified adult male subjects. These study subjects were members of three different groups, two of which had overlapping home ranges. During a focal follow, a subject was filmed for 15 minutes regardless of their activity. If the subject engaged in SH during the last two minutes of the observation, the observation was continued for an additional five minutes or until SH ceased and then continued for an additional two minutes after the subject was no longer engaged in SH (cf. Huffman, 1996). *Ad libitum* sampling began when a subject was engaged in SH, and continued for two minutes after the subject was no longer engaged in SH. When possible, focal subjects were filmed from the front or side so their face, torso, and limbs were visible, approximately 3-5 meters away from the observer. Data were collected using a Sony Handycam Camcorder.

Data analysis

Data analysis was done using Motifs, a short-hand form of notation used in LMA. Motifs were made from video recordings of acts (i.e., a singular rub or pound) composing SH sequences. From the Motifs, two rating scales, one for rubbing and one for pounding, were derived to score the presence or absence of movements components (i.e., measures) in additional SH sequences.

Ethical Statement

All data were collected using observational and non-invasive methodologies. This study was conducted in accordance with the Indonesian Ministry of Research and

Technology (research permit #130/SIP/FRP/E5/Dit.KI/IV/2018), the Provincial Government of Bali, and the local district authorities. It was approved by the Institutional Animal Welfare Committee of the University of Lethbridge (Protocol #1906).

Rubbing and Pounding

The rubbing SH pattern is defined as, "To slide or move a stone back and forth on a substrate utilizing a power or precision grip" (p.471) (Pelletier et al., 2017). The rubbing SH pattern can be performed on the ground or other substrates including the individual's own body. The pounding SH pattern is defined as, "To strike a stone on the ground or an object, using a power grip" (p. 470) (Pelletier et al., 2017). Stones are often pounded on hard surfaces. Previous research has identified three movement phases of a pound including the upswing, adjustment, and downswing (Pelletier, 2017).

Terminology

An act is the elementary building block of a behavioural sequence and may consist of multiple movements (Eilam, 2015). In the present study, an act is defined as either a single rub or a single pound. For rubbing, one act is when a subject moves the stone away from their body and then moves it back towards their body while the stone remains on the substrate. For pounding, one act is when a subject moves the stone up and off the ground and then moves it back down towards the ground. Within an act, there are phases. Phases are groupings of movements, such as the upswing of a pound. The movements that compose a phase are called measures. The phases and measures are dictated by the Motifs. The subsequent sections will detail the process of notating the Motifs and identifying the phases and measures for the rubbing and pounding SH patterns.

Study Part 1 – Methods

Subjects

Five adult male subjects were selected for this study (Table 2.1). Three subjects who engaged in rubbing and two subjects who engaged in pounding.

Laban Movement Analysis

LMA, developed by Rudolf Laban, is a language system for describing the holistic, multi-nested and dynamically integrative aspects of movement by notating what the body is doing, how the body is doing it, when the body is doing it, and the way the body moves relative to itself, external objects, and other individuals (Bartenieff & Lewis, 1980; Foroud & Pellis, 2003; Foroud & Whishaw, 2006). LMA goes beyond providing an objective language for recording body movements, it describes *how* the body moves. For example, instead of limiting description to that of a limb moving from point A to point B over a specific duration of time, changes in the spatial-temporal organization of the limb, and its interactions with other limbs, as well as the relationship(s) between the body and environment are defined. Furthermore, changes in the quality of movement such as intensity, force, flow, and rhythm of the limb and body are objectively described. This multi-layered approach to describing movement reveals patterns of how the body interacts with the environment, including objects and other individuals.

LMA is composed of four distinct yet dynamically integrated categories: Body, Effort, Shape, and Space (may be abbreviated to BESS) (Bartenieff & Lewis, 1980; Foroud & Pellis, 2003). A movement may express elements from BESS in various combinations and interactions of these categories. For this initial analysis, Body, Effort, and Space were examined. LMA uses a series of symbols to notate movement – similar to the way a musical composition is written so that it can be read and replicated. For a list and explanation of commonly used symbols, see Appendix A. For clarity, all terms relating to LMA are capitalized. The following section will briefly describe each of the three categories of LMA used in this thesis:

1. ***Body*** focuses on the anatomical features of the body, such as the skeletal muscular system and joint systems. Body also describes the relationship between the limbs (including torso and head), the body as a whole, and other bodies or objects (Bartenieff & Lewis, 1980; Foroud & Pellis, 2003; Foroud & Whishaw, 2006).
2. ***Space*** encompasses the dynamic relationship between the body and the surrounding environment such as the direction and pathways the body moves in space and how the body changes in response to the surrounding space and environment (Bartenieff & Lewis, 1980; Foroud & Pellis, 2003; Foroud & Whishaw, 2006).
3. ***Effort*** classifies changes in exertion of energy throughout a movement. It captures the intensity and is often perceived as qualitative elements of movement. Effort Qualities range from Indulging, in which there is a release of intensity or exertion within the movement, to Condensing, in which there is increasing intensity or exertion within the movement. Effort Qualities are not a reflection of the active or passive engagement of the subject. Rather, they encompass changes in exertion of energy within the movement. Effort Qualities include Weight Effort (force), Flow Effort (tension), Time Effort (acceleration), and Space Effort (quality of directionality). Each Effort Quality

is a gradient, again ranging from Indulging to Condensing. The following subsection will provide a further explanation of each Effort Quality. The definitions and examples provided are from Bartenieff and Lewis (1980) as well as Foroud and Whishaw (2006). Effort Qualities are operationally defined through supervised repeated observation, practice, and evaluation until the observer can consistently identify and perform each Effort Quality (Laban & Ullmann, 1971). Fagan et al. (1997) described the process of having students identify Effort Qualities present across multiple behavioural categories (e.g., locomotion, object manipulation) performed by multiple species of non-human animals (e.g., gorillas, brown bears). The study demonstrated the validity of observing Effort Qualities.

[1] **Weight Effort:** Weight Effort is the change of force exerted throughout a movement. Light Weight Effort, an Indulging Effort Quality, describes diminishing exertion of force. For example, when handling a delicate item such as a teacup, it is effective to use Light Weight Effort. Strong Weight Effort, a Condensing Effort Quality, describes an increase in the exertion of force, or impact in a movement. For example, crushing an item, such as a teacup, in your hand would likely utilize Strong Weight Effort.

[2] **Flow Effort:** Flow Effort describes the increasing or decreasing level of resistance in the continuity of a movement. Free Flow, an Indulging Effort Quality, appears effortless and easy going. For example, a child might move with Free Flow as they spin in circles

and fall down into the grass. Bound Flow, a Condensing Effort Quality, is controlled and restrained. For example, a child might move with Bound Flow as they pump their legs to build momentum on a swing. Flow Effort is not the same as the state of flow coined by Mihaly Csikszentmihalyi (1990). The state of flow will be further elaborated on in Chapter Four.

[3] **Time Effort**: Time Effort reflects an exertion in the change of velocity by either acceleration or deceleration. Time Effort does not reflect the duration or speed of a movement, but rather the change in speed of the movement. Sustained Time, an Indulging Effort Quality, occurs when the mover progressively decelerates the movement. For example, waving goodbye to a friend that is leaving for a long time often occurs with Sustained Time. Quick Time, a Condensing Effort Quality, occurs when the mover progressively accelerates the movement. For example, trying to catch a fly in your hand often occurs with Quick Time.

[4] **Space Effort**: Space Effort describes the body's attention to space through a movement. Indirect Space, an Indulging Effort Quality, is when the body is multi-focused. For example, waving a bunch of gnats away from your face occurs with Indirect Space. Direct Space, a Condensing Effort Quality, is when the body is zero-ed in on something specific. For example, plucking an eyebrow hair occurs with Direct Space.

The kinematic structure of a behaviour consists of how the limbs move, how the limbs move relative to one another and the environment (including other animals), and the temporal relationships of these movements (e.g., pronation of the foot as an individual places their foot on the ground) (Bartenieff & Lewis, 1980; Foroud & Pellis, 2003; Foroud & Whishaw, 2006). Non-kinematic qualities of movement also shapes how the body moves, for example, the change in exertion of energy throughout a movement, and are difficult to measure objectively, or even describe consistently and reliably. LMA provides a language system, with operational definitions for movement qualities embedded in the language, as a means to objectively describe and potentially measure the dynamics of kinematic and non-kinematic qualities expressed in movement. Regarding the BESS categories of LMA, Body and Space are often categorized as kinematic movements whereas Effort and Shape are often categorized as non-kinematic qualities of movements (Foroud & Whishaw, 2006). Kinematic and non-kinematic elements of a behaviour are not mutually exclusive and often occur simultaneously with non-kinematic qualities potentially supporting or hindering the movements. It should be noted that while Effort Qualities mostly consist of non-kinematic qualities, Time Effort consists of a kinematic element of movement – acceleration/deceleration.

Motifs

The aim of this study was to gain a further understanding of the movement composition of two SH patterns, rubbing and pounding. To do this, I used LMA to identify movement patterns and qualities of SH in five different subjects, three subjects who engaged in rubbing and two subjects who engaged in pounding (Figure 2.1 and Figure 2.2). LMA describes Body, Effort Qualities, Shape, and Space, and their interrelations (Bartenieff & Lewis, 1980; Foroud & Whishaw, 2006). Motifs, a shorthand notation used in LMA, allow the observer to gain a view of the way the kinematic components and non-kinematic components of movement interact throughout a movement or a movement sequence over time.

LMA was used to analyse movement sequences of three SH sequences from each subject resulting in a total of 15 Motifs. Each Motif described multiple acts within a SH sequence. Subjects and SH bouts were selected based on the following criteria: [1] subjects were classified as adults, [2] subjects had no new or obvious injuries that may impede movements involved with rubbing or pounding (e.g., had recently broken a finger), [3] the stones must all be small enough that the subject was able to pick up the stone with one hand but not so small that the stone could not be seen in the subject's hand (e.g., a stone approximately between three and a half and ten centimeters in length), [4] the substrates (e.g., the forest floor or the pathway built for tourists) on which the subject was engaged in SH needed to be similar, meaning that there were no obvious factors that would impede typical movements (e.g., large cracks in the ground), and [5] all SH sequences were performed in a neutral state. A neutral state was defined as a state in which the subject was not exhibiting any displacement behaviours, aggressive, or submissive signals within one minute prior to engaging in SH (for review of typical displacement behaviours exhibited by non-human primates, see Troisi, 2002).

In order to describe the movement composition of a SH pattern performed in the rougher/rigid manner (hereafter RP for Rougher Performance) and the gentler/fluid manner (hereafter GP for Gentler Performance), SH sequences (truncated from the previously selected SH bouts) were selected using the following process (Figure 2.3): [1]

a portion of a SH sequence in which the subject appeared to be performing either rubbing or pounding in the gentler/fluid manner was identified, [2] within the same SH sequence, a portion of the SH sequence in which the subject was engaging in the same SH pattern in what appeared to be the rougher/rigid manner (RP1) 20 seconds *before* the beginning of the gentler/fluid performance (GP) was selected, [3] within the same SH sequence, a portion of the SH sequence in which the subject was engaging in the same SH pattern in what appeared to be the rougher/rigid manner 20 seconds *after* the beginning of the gentler/fluid performance was selected (RP2). Two samples of the rougher/rigid performance were selected from each SH sequence to address whether the sequence of the rubs or pounds were contributing to the rougher/rigid performance.

Once the Motifs were notated, I wrote out what each Motif described. There are three main reasons for this step. First, writing out what was notated in the Motif allows for other researchers to understand the Motif without having to know LMA. Second, watching a behaviour and writing out what we see can be subjective. By using LMA, I was able to have a more objective viewing of the video before writing it out in a language I was more familiar with. Third, as I am still learning LMA, I needed to write out the Motifs to practice reading the language of LMA as well as improve my understanding of the Motif. After this step, the combination of the completed Motifs, with their corresponding written descriptions, was used to list the essential elements described in the Motifs, in sequential order. These elements became the measures (i.e., movements) for rubbing and pounding respectively. Measures are defined as the individual movements described in the Motifs. The measures were listed sequentially because they were derived from the Motifs which provided not only a list of movements that create the rubbing and pounding SH patterns, but also the temporal relationships between the movements. The measures listed (e.g., Face orientated towards the stone) describe the movements that make up the acts. The measures in the list and the way the list is used to score the behaviour, define both how the movements were performed and the temporal order in which the movement was performed. For example, “Face orientated towards the stone” is listed as it appeared in the notated Motifs (which were developed by watching the video recordings of multiple SH sequences) (see Appendix B). While it was possible to have added the converse of each measure in the rating scale (e.g., Face orientated towards the stone vs. Face orientated away from the stone), that would not have been accurate to the Motifs which are a notation of the video sequences. I made the decision to have the rating scale reflect how the rougher performances tend to be performed because the rougher/rigid performances are the more recognizable performance of SH. The Motifs, and subsequent rating scales, capture the kinematic and non-kinematic components that compose the behaviour rather than capturing the movements that did not occur. If I were to have added the converse of each movement, I would be speculating on possible alternative movements that were not presented in the video sequence. For example, the converse movement to “Wrist flexes as hand moves away from torso” is not necessarily “Wrist extends as hand moves away from torso” and therefore, without having seen the converse movement in the video recording, it would not be accurate to include it in the rating scales.

These rating scales are referred to as the Rubbing Rating Scale (RRS) and Pounding Rating Scale (PRS) respectively. These steps (i.e., writing out the Motifs, combining the movement components of the Motifs, and itemizing the Motifs into rating scales) were essential to ensuring an objective analysis of the RP and GP of the rubbing and pounding SH patterns. By combining the completed Motifs, I was able to develop two rating scales that encompassed movements present in the RP and GP of the two SH patterns. This allows for future analyses of the rubbing and pounding SH patterns. The measures were placed into six phases specific to rubbing and pounding (Figure 2.4 and Figure 2.5); this allowed me to analyse each SH pattern as its "parts" (i.e., the phases and measures) and as a "whole" (the combined picture painted by the sequential phases and their subsequent measures). The phases were based on previous work by Pelletier (2017) which identified the three main phases of a pound as the upswing, adjustment, and downswing. Additionally, the Motifs described the phases for both the rubbing and pounding SH patterns. Fentress (1992) stated the importance of a "pluralistic" approach when studying behaviours to optimize our capacity for recognizing the "rules" of organization within a behaviour (p. 1531). For example, by placing measures into their specific phases, we can understand how the measures relate to one another as well as how each phase of movement relates to the next and so on. The phases were based on previous research on the pounding SH pattern (Pelletier, 2017).

Each notated act was then scored using the respective rating scales. If the measure occurred in the phase, it received a score of 1. If the measure did not occur, then it received a score of 0. In doing so, we were able to refine the list of measures by combining redundant and extra measures. For example, "movement in vertical plane" and "movement in sagittal plane" were two measures that were removed because a rub occurs when a subject moves the stone on the substrate in the horizontal plane; therefore, the measures were not necessary. Additionally, two or more measures which originally described the range of one measure were combined. For example, "proximally initiated" and "not distally initiated" were different ways of describing the same thing; thus, one was removed as both measures were not necessary in the rating scale to represent this structural component of the "Outward" phase. Reducing the list of measures allows for the concise quantification of the structural elements composing rubbing and pounding. These extra, redundant, measures were in the sequential lists of measures because, as I am still learning LMA, I needed to consider other possible variations of movements that I had not observed in the Motifs.[1]

These rating scales, developed from the Motifs, provide a method for quantifying the occurrence, sequence, and qualities of movements composing the two different SH patterns. Each rating scale consisted of six phases and their corresponding measures. The six phases and corresponding measures compose either the rubbing or pounding act. The rating scales are valuable as they provide a method for testing future hypotheses about the rubbing and pounding SH patterns. Each phase and the subsequent measures for both rubbing and pounding are defined below in the sequential order of a rub or pound.

Study Part 1- Results

Rubbing Rating Scale

This rating scale consisted of six phases of movements visible in a single rub (i.e., act): starting orientation, outward, first adjustment, inward, second adjustment, and ending orientation. Within each phase, there are movements (i.e., measures) that compose

[1] As a beginner student of LMA, I was not confident that the Motifs I had done fully captured all of the movements in the SH acts. Therefore, I had originally added what I thought could be potential variations of movements into the rating scales until I gained more experience in watching the video recordings and scoring the SH sequences.

that phase of a rub. Each movement will be further described in the following text and again in Appendix B.

[1] Starting Orientation – This phase encompasses the starting position of the subject at the beginning of a rubbing act (this phase, and corresponding measures, can occur at the start of a SH bout or within a SH sequence, meaning the subject may already have been engaged in SH).

[1.1] Face oriented towards stone: The subject's forehead and face are pointed at the stone they are manipulating.

[1.2] Body orientated towards stone: The midline of the subject's torso is pointed at the stone they are manipulating.

[2] Outward (Away from the body) – This phase encompasses the main movements that compose the outward motion of the forelimb(s), in which the subject manipulates the stone away from their body, creating more distance between their torso and the stone.

[2.1] Torso & limb movement are synchronized: The subject's torso and the limb manipulating the stone move together at the same time; the torso supports the limb, moving in coordination with the limb, as the stone is moved outward away from the subject's body.

[2.2] Distally initiated (wrist & hand): The outward limb movement begins with a movement from either the subject's wrist or their hand. The wrist or hand moves first rather than the elbow, shoulder, or torso.

[2.3] Wrist flexes as hand moves away from torso: As the subject moves their hand away from their body, the wrist bends so that the distance between the palm of the hand and the underside of the forearm shortens.

[2.4] Fingers extend as hand moves away from torso: As the subject moves their hand away from their body, the fingers lengthen out, decreasing the bend at the knuckles.

[2.5] Hand moves in a straight pathway: As the subject moves their hand away from their body, the hand moves straight, with no curves or meandering.

[2.6] Proportion of Condensing Effort Qualities exceeds Indulging Effort Qualities: Throughout the entire outward phase of movement, there are more Condensing Effort Qualities (Strong Weight, Bound Flow, Quick Time, and Direct Space) than Indulging Effort Qualities (Light Weight, Free Flow, Sustained Time, and Indirect Space). This measure did not focus on the specific Effort Qualities and instead focused on the gradient they stem from, Condensing to Indulging. Effort Qualities cannot be perceived by viewing a video frame-by-frame. To quantify the Effort Qualities, the video must be viewed at its normal speed.

[3] First Adjustment – Following the outward phase, this phase encompasses the main movements that occur when the stone was no longer moving farther away from the body but was not yet moving back towards the body. During

this phase, movements appeared to be small positioning changes on the stone, while the stone remained in one location.

[3.1] Wrist and/or fingers extend: Either the subject's wrist or fingers extend; for the wrist this looks like the distance between the back of the hand and the backside of the forearm shortens; for the fingers, this looks like the fingers are lengthening out, decreasing the bend at the knuckles.

[3.2] Supination: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces upwards or forwards.

[3.3] Release of contact with stone as hand lifts: The subject may make small movements in the adjustment phase, one of them being releasing the stone prior to grabbing the stone again. If their hand is no longer touching the stone after loosening their grasp, they have then released contact with the stone.

[3.4] Pronation: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces downwards or backwards.

[3.5] Re-contact with stone as hand lowers: If the subject did not engage in measure 3.3, then they cannot score a 1 for this measure. If they did engage in measure 3.3, and they return their hand to the stone, they have regained contact with the stone.

[3.6] Wrist and/or fingers flex: Either the subject's wrist or fingers flex;

for the wrist this looks like the distance between the palm of the hand and the underside of the forearm shortens; for the fingers, this looks like the fingers bend, increasing the bend at the knuckles.

[3.7] Lateral deviation at the wrist: The subject's wrist bends either to the left or the right; the hand does not move in the vertical plane meaning the palm of the hand neither gets closer to the underside of the forearm nor farther from it.

[4] Inward (Towards the body) – This phase encompasses the main movements that compose the inward motion, in which the subject manipulates the stone towards their body, creating less distance between their torso and the stone.

[4.1] Torso & limb movement are synchronized: The subject's torso and limb manipulating the stone move together at the same time; the torso supports the limb, moving in coordination with the limb, as the stone is moved inward, towards the subject's body.

[4.2] Distally initiated: The inward movement begins with a movement from either the subject's wrist or their hand. The wrist or hand moves first rather than the elbow, shoulder or torso.

[4.3] Wrist extends as hand moves towards torso: As the subject moves their hand towards their body, the wrist bends so that the distance between the back of the hand and the backside of the forearm shortens.

[4.4] Fingers flex as hand moves towards torso: As the subject moves their hand towards their body, the fingers bend, increasing the bend at the knuckles.

[4.5] Hand moves along a straight pathway: As the subject moves their hand towards their body, the hand moves straight, with no curves or meandering.

[4.6] Proportion of Condensing Effort Qualities exceeds Indulging Effort Qualities: Throughout the entire inward phase of movement, there are more Condensing Effort Qualities (Strong Weight, Bound Flow, Quick Time, and Direct Space) than Indulging Effort Qualities (Light Weight, Free Flow, Sustained Time, and Indirect Space). This measure did not focus on the specific Effort Qualities and instead focused on the gradient they stem from, Condensing to Indulging. Effort Qualities cannot be perceived by viewing a video frame-by-frame. To quantify the Effort Qualities, the video must be viewed at its normal speed.

[5] Second Adjustment – Following the inward phase, this phase encompasses the main movements that occur once the stone has been brought inwards, towards the subject's body but before the subject either ceases to handle the stone or initiates another rub. During this phase, movements appeared to be small positioning changes on the stone, while the stone remained in one location. In this phase, for the measures to receive a score of 1, they must happen in the listed order. For example, if measure 5.2 occurred after measure 5.4, it would still

receive a score of 0. The exception is measure 5.6, which could receive a 1 independent of the order of occurrence.

[5.1] Wrist and/or fingers extend: Either the subject's wrist or fingers extend; for the wrist this looks like the distance between the back of the hand and the backside of the forearm shortens; for the fingers, this looks like the fingers are lengthening out, decreasing the bend at the knuckles.

[5.2] Supination: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces upwards or forwards.

[5.3] Release of contact with stone as hand lifts: The subject may make small movements in the adjustment phase, one of them being releasing the stone prior to grabbing the stone again. If their hand is no longer touching the stone after loosening their grasp, they have then released contact with the stone.

[5.4] Pronation: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces downwards or backwards.

[5.5] Re-contact with stone as hand lowers: If the subject did not engage in measure 5.3, then they cannot score a 1 for this measure. If they did engage in measure 5.3 and they return their hand to the stone, they have regained contact with the stone.

[5.6] Lateral deviation at the wrist: The subject's wrist bends either to the left or the right; the hand does not move in the vertical plane meaning the palm of the hand neither gets closer to the underside of the forearm nor farther from it.

[6] Ending orientation – This phase encompasses the ending position of the subject at the end of a rubbing act regardless of whether the subject continued to engage in SH, or if they ceased to perform SH.

[6.1] Face oriented towards stone: The subject's forehead and face are pointed at the stone they are manipulating.

[6.2] Body oriented towards stone: The midline of the subject's torso is pointed at the stone they are manipulating.

Pounding Rating Scale

This rating scale consisted of six phases of movements visible in a single pound (i.e., act): starting orientation, upswing, adjustment, downswing, transition, and ending orientation. Within each phase, there are movements (i.e., measures) that compose that phase of a pound. Each measure will be further described in the following text and again in Appendix B.

[1] Starting Orientation – This phase encompasses the starting position of the subject at the beginning of a pounding act.

[1.1] Face oriented towards stone: The subject's forehead and face are pointed at the stone they are manipulating.

[1.2] Body orientated towards stone: The midline of the subject's torso is pointed at the stone they are manipulating.

[2] Upswing – This phase encompasses the main movements that compose the

upward motion, in which the subject manipulates the stone off and away from the ground.

[2.1] Torso & limb movement are synchronized: The subject's torso and limb manipulating the stone move together at the same time; the torso supports the limb, moving in coordination with the limb, as the stone is lifted off of the ground.

[2.2] Distally initiated (wrist and hand): The upward movement begins with a movement from either the subject's wrist or their hand. The wrist or hand moves first rather than the elbow, shoulder, or torso.

[2.3] Wrist flexes as hand moves away from the ground: As the subject lifts the stone off of the ground, the wrist bends so that the distance between the palm of the hand and the underside of the forearm shortens.

[2.4] Fingers flex as hand moves away from the ground: As the subject lifts the stone off of the ground, the fingers bend, increasing the bend at the knuckles.

[2.5] Supination: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces upwards or forwards.

[2.6] Movement in either vertical or sagittal plane: As the subject raises their arm with the stone away the ground, the movement remains in either the vertical or sagittal plane.

[2.7] Proportion of Condensing Effort Qualities exceeds Indulging Qualities: Throughout the entire upward phase of movement, there are more Condensing Effort Qualities (Strong Weight, Bound Flow, Quick Time, and Direct Space) than Indulging Effort Qualities (Light Weight, Free Flow, Sustained Time, and Indirect Space). This measure did not focus on the specific Effort Qualities and instead focused on the gradient they stem from, Condensing to Indulging. To quantify the Effort Qualities, the video must be viewed at its normal speed.

[3] Adjustment – Following the upswing phase, this phase encompasses the main movements that occur at the highest point of the upswing phase when the stone was no longer moving in the vertical or sagittal plane. During this phase, movements appeared to be small positioning changes on the stone, prior to the downswing phase.

[3.1] Forelimb rotation: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces upwards or forwards (i.e., supination) or so that the palm faces downwards or backwards (i.e., pronation).

[3.2] Wrist extends and/or flexes: The subject's wrist bends so that the distance between the back of the hand and the backside of the forearm shortens (i.e., extension) or so that the distance between the palm of the hand and the underside of the forearm shortens (i.e., flexion).

[3.3] Fingers extend and/or flex: The subject's fingers bend so that the fingers are lengthening out, decreasing the bend at the knuckles (i.e., extension) or so that the fingers bend, increasing the bend at the knuckles (i.e., flexion).

[3.4] Lateral deviation at the wrist: The subject's wrist bends either to the left or the right, the hand does not move in the vertical plane meaning the palm of the hand neither gets closer to the underside of the forearm nor farther from it.

[4] Downswing – This phase encompasses the main movements that compose the downward motion, in which the subject manipulates the stone closer to the ground, eventually completely returning the stone to the ground.

[4.1] Torso & limb movement are synchronized: The subject's torso and limb manipulating the stone move together at the same time; the torso supports the limb, moving in coordination with the limb, as the stone is returned to the ground.

[4.2] Distally initiated (wrist and hand): The downward movement begins with a movement from either the subject's wrist or their hand. The wrist or hand moves first rather than the elbow, shoulder or torso.

[4.3] Wrist extends as the hand moves towards the ground: As the subject moves the stone towards the ground, the wrist bends so that the distance between the back of the hand and the backside of the forearm shortens.

[4.4] Fingers extend as the hand moves towards the ground: As the subject moves the stone towards the ground, the fingers lengthen out, decreasing the bend at the knuckles.

[4.5] Pronation: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces downwards or backwards.

[4.6] Movement in either vertical or sagittal plane: As the subject lowers their arm with the stone towards the ground, the movement remains in the vertical or sagittal plane.

[4.7] Proportion of Condensing Effort Qualities exceeds Indulging Qualities: Throughout the entire downward phase of movement, there are more Condensing Effort Qualities (Strong Weight, Bound Flow, Quick Time, and Direct Space) than Indulging Effort Qualities (Light Weight, Free Flow, Sustained Time, and Indirect Space). This measure did not focus on the specific Effort Qualities and instead focused on the gradient they stem from, Condensing to Indulging. To quantify the Effort Qualities, the video has to be viewed at its normal speed.

[5] Transition – Following the downswing phase, this phase encompasses the main movements that occur once the stone is touching the ground, but before the subject either ceases to perform SH or initiates another pound. During this phase, movements appeared to be small positioning changes on the stone, while the stone remained in one location. During this phase, for the measures to receive a score of 1,

they must happen in the listed order. For example, if measure 5.2 occurred after 5.4, it would still receive a score of a 0. The exception is measure 5.7 which could receive a 1 independent of the order of occurrence.

[5.1] Wrist and/or fingers extend: Either the subject's wrist or fingers extend; for the wrist, this looks like the distance between back of the hand and the backside off the forearm shortens; for the fingers, this looks like the fingers are lengthening out, decreasing the bend at the knuckles.

[5.2] Supination: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces upwards or forwards.

[5.3] Release of contact with stone as hand lifts: The subject may make small movements in the adjustment phase, one of them being releasing the stone prior to grabbing the stone again. If their hand is no longer touching the stone after loosening their grasp, they have then released contact with the stone.

[5.4] Pronation: The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces downwards or backwards.

[5.5] Re-contact with stone as hand lowers: If the subject did not engage in measure 5.3, then they cannot score a 1 for this measure. If they did engage in measure 5.3 and they return their hand to the stone, they have regained contact with the stone.

[5.6] Wrist and/or fingers flex: Either the subject's wrist or fingers flex;

for the wrist, this looks like the distance between the palm of the hand and the underside of the forearm shortens; for the fingers, this looks like the fingers bend, increasing the bend at the knuckles.

[5.7] Lateral deviation at the wrist: The subject's wrist bends either to the left or the right; the hand does not move in the vertical plane meaning the palm of the hand neither gets closer to the underside of the forearm nor farther from it.

[6] Ending Orientation – This phase encompasses the ending position of the subject at the ending of a pounding act regardless of whether the subject continued to engage in SH, or if they ceased to perform SH.

[6.1] Face orientated towards stone: The subject's forehead and face are pointed at the stone they are manipulating.

[6.2] Body orientated towards stone: The midline of the subject's torso is pointed at the stone they are manipulating

Study Part 2 Methods- Rating Scales

Subjects

For the rubbing SH pattern, three adult male subjects were selected. A total of 73 acts were scored (Table 2.2). For the pounding SH pattern, three adult male subjects were selected. A total of 101 acts were scored (Table 2.3).

Scoring

To further examine the structural variations seen within rubbing and within pounding, numerous samples of the RP1, RP2, and GP were scored using the Rubbing Rating Scale and Pounding Rating Scale. The same selection protocol used for the Motif selection was used to select the SH sequences; however, the number of acts in a SH sequence was not a selection criterion (e.g., some SH sequences contained 3 acts and some contained 5 acts).

Following analyses comparing RP1, RP2, and GP, additional SH sequences were scored. SH sequences were separated into two categories. The first category included SH sequences that appeared to be the rougher/rigid presentation (RP) of the pattern. The second category included the SH sequences that appeared to be the gentler/fluid presentation (GP) of the pattern. For the rubbing SH pattern, seven adult male subjects were selected. A total of 90 acts were scored (Table 2.4). For the pounding SH pattern, 11 adult male subjects were selected. A total of 110 acts were scored (Table 2.5). SH sequences containing the individual acts were selected based on the same protocol used for the Motif selection; however, the order of occurrence of the RP vs. the GP was irrelevant, as well as the number of acts within the SH sequences.

All scoring was done by reviewing each act frame-by-frame and regular speed repeatedly. As each act was reviewed, it was scored using the corresponding rating scale. If the measure occurred in the way it was defined, then a 1 was scored. If the measure did not occur, then a 0 was scored. For specific definitions of each measure, see Appendix B.

For both rubbing and pounding, an intra-scorer reliability test was conducted.

Statistical Analyses

All statistical analyses were performed for the rubbing SH pattern and pounding SH pattern separately. A series of odds ratios and two-sample Kolmogorov-Smirnov tests (K-S tests) were conducted to compare the RP and GP of the rubbing and pounding SH patterns. An odds ratio is typically used to compare the odds of occurrence of a behaviour based on the variable of interest. An odds ratio of 1 indicates that there was no effect due to the variable analysed. An odds ratio less than and greater than 1 indicates that there was an effect due the variable analysed. In this study, the number of times the subject scored a 1 was divided by the total number of times the subject scored a 0 as indicated by the respective rating scales. The odds ratio was then calculated by dividing the previously described values for two different variations such as (ex. $\frac{Number\ of\ times\ subject\ scored\ a\ 1\ \div number\ of\ times\ subject\ scored\ a\ 0\ in\ the\ RP}{Number\ of\ times\ subject\ scored\ a\ 1\ \div number\ of\ times\ subject\ scored\ a\ 0\ in\ the\ GP}$). For this study, an odds ratio exceeding a value of 1 indicates that the subject was more likely to perform the measures in the rating scale (i.e., Rubbing Rating Scale or Pounding Rating Scale) when performing the performance type of interest (e.g., RP). An odds ratio of 1 indicated that there was no effect due to the version being analysed (e.g., RP). An odds ratio less than 1 indicated that the subject was likely to perform fewer of the measures in the rating scale when performing the version of interest (e.g., RP). The 95% confidence interval was calculated as $e^{\ln(\mathrm{OR}) \pm 1.96\sqrt{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}+\frac{1}{d}}}$ where e is the mathematical constant for the natural log, ln is the natural log, and where *a* is the number of times subjects scored a 1 in the RP, *b* is the number of times subjects scored a 0 in the RP, *c* is the number of times subjects scored a 1 in the GP, and *d* is the number of times a subject scored a 0 in the GP. The z-score required to obtain a p-value was calculated as $\ln(\mathrm{OR})/\sqrt{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}+\frac{1}{d}}$.

The two-sample K-S test is a non-parametric analysis used to compare two distributions. To develop the distributions, data were filtered within subject, then by variation, and then by each phase of movement. Within each phase, the total number of times an individual scored a 1 for each measure was divided by the total number of times an individual *could* have scored a 1 for this measure. This resulted in a proportion representing the rate of occurrence of each measure, within each phase, for each subject. These proportions, from each subject, created the distributions that were used in the series of K-S tests. All subjects were weighted equally. Only one value per subject was included in the distribution.

A Cohen's kappa coefficient was calculated to determine intra-scorer reliability. The closer the coefficient is to 1, the stronger the level of agreement is (Cohen, 1960). Significance levels were set at $\alpha = 0.05$. Analyses were done using R 3.6.2 (R Core Team, 2020; Wickham, 2016; Wickham et al., 2019), MedCalc Software[2], and manual calculations.

Study Part 2 – Results

The RRS and PRS were developed using Motifs. These scales list both the kinematic and non-kinematic motor components of the rubbing SH pattern and pounding SH pattern. The results from the odds ratio may be a statistical artifact, specifically a Type I error due to how the data were aggregated across subjects rather than within subject. Due to the aggregation of data across subjects, the subjects are not weighted equally and there is pseudo-replication in the data set. To remove bias, the data should not be aggregated across subjects. In contrast, the K-S tests were conducted using distributions derived from proportions that accounted for differences in the number of acts scored per subject by using averages. Therefore, I primarily relied on the K-S tests

[2] MedCalc Software Ltd. Odds ratio calculator. https://www.medcalc.org/calc/odds_ratio.php

when interpreting the results. However, as the two-sample K-S test only identifies *if* there is a significant difference between two distributions, odds ratios were reported because they identify the directionality of the difference between the two distributions.

Rubbing

Three odds ratios were calculated to compare each type of performance (RP vs. GP) to each other. When performing RP1, subjects were more likely to perform the measures in the RRS than when performing the GP; the odds ratio was $\frac{327 \div 243}{266 \div 394}$ = 1.99 (95% CI: 1.59 – 2.50, $p < 0.05$). When performing the RP1 of the rubbing SH pattern and the RP2 of the rubbing SH pattern, subjects were equally likely to perform the measures in the RRS; the odds ratio was $\frac{327 \div 243}{533 \div 427}$ = 1.08 (95% CI: 0.87 – 1.33, $p > 0.05$). When performing the GP, subjects were less likely to perform the measures in the RRS than when performing the RP2 of the rubbing SH pattern; the odds ratio was $\frac{266 \div 394}{533 \div 427}$ = 0.54 (95% CI: 0.44 – 0.66, $p < 0.05$). Following these results, the RP1 and RP2 performances were no longer separated based on their temporal location in the SH sequences.

When analysing the similarities and differences between the RP and the GP, an odds ratio was calculated comparing the variations as a whole and then each movement phase was analysed separately (Figure 2.6). When performing the RP, subjects were more likely to perform the measures in the RRS than when performing the GP; the odds ratio was $\frac{687 \div 663}{467 \div 883}$ = 1.96 (95% CI: 1.68 – 2.29, $p < 0.05$).

There was a statistically significant difference in the distributions of the RP and the GP for the "Orientation" phase (K-S test, $D_{(m,n = 7)} = 1.00$, $p < 0.05$). The odds ratio was $\frac{82 \div 8}{41 \div 49}$ = 12.25 (95% CI: 5.31-28.27, $p < 0.05$). There was no statistically significant difference in the distribution of the RP and the distribution of the GP for the "Outward" phase (K-S test, $D_{(m,n = 7)} = 0.71$, $p > 0.05$). The odds ratio was $\frac{184 \div 86}{120 \div 150} = 2.67$ (95% CI: 1.88-3.80, $p < 0.05$). There was no statistically significant difference in the distributions of the RP and the GP for the "First Adjustment" phase (K-S test, $D_{(m,n = 7)} = 0.43$, $p > 0.05$). The odds ratio was $\frac{77 \div 238}{61 \div 254} = 1.35$ (95% CI: 0.92 – 1.97, $p > 0.05$). There was no statistically significant difference in the distributions of the RP and the GP for the "Inward" phase (K-S test, $D_{(m,n = 7)} = 0.57$, $p > 0.05$). The odds ratio was $\frac{185 \div 85}{144 \div 126} = 1.90$ (95% CI: 1.34 – 2.70, $p < 0.05$). There was no statistically significant difference in the distributions of the RP and the GP for the "Second Adjustment" phase (K-S test, $D_{(m,n = 7)} = 0.43$, $p > 0.05$). The odds ratio was $\frac{75 \div 240}{59 \div 256} = 1.36$ (95% CI: 0.92 – 1.99, $p > 0.05$). There was a statistically significant difference in the distributions of the RP and the GP for the "Ending Orientation" phase (K-S test, $D_{(m,n =7)} = 0.86$, $p < 0.05$). The odds ratio was $\frac{84 \div 6}{42 \div 48} = 16.00$ (95% CI: 6.33 – 40.39, $p < 0.05$). The intra-scorer reliability for the rubbing SH pattern was Kappa = 0.75.

Pounding

Three odds ratios were calculated to compare each variation to each other. When performing the RP1 of the pounding SH pattern, subjects were more likely to perform the measures in the PRS than when performing the GP; odds ratio was $\frac{526 \div 554}{323 \div 487} = 1.43$ (95% CI: 1.19 - 1.72, $p < 0.05$). When performing the RP1 of the pounding SH pattern, subjects were equally likely to perform the measures in the PRS than when performing the RP2 of the pounding SH pattern; the odds ratio was $\frac{526 \div 554}{418 \div 422} = 0.96$ (95% CI: 0.80 – 1.15, $p > 0.05$). When performing the GP, subjects were less likely to perform the measures in the

PRS than when performing the RP2; the odds ratio was $\frac{323 \div 487}{418 \div 422}$ = 0.67 (95% CI: 0.55 – 0.81, $p < 0.05$). Following these results, the first and second rougher/rigid performances were no longer separated based on their temporal location in the SH sequences.

When analysing the similarities and differences between the RP and the GP, an odds ratio was calculated comparing the variations as a whole and then each movement phase was analysed separately (Figure 2.7). When performing the RP, subjects were more likely to perform the measures in the PRS than when performing the GP; the odds ratio was $\frac{882 \div 768}{720 \div 930}$ = 1.48 (95% CI: 1.29 – 1.70, $p < 0.05$).

There was a statistically significant difference in the distributions of the RP and the GP for the “Orientation” phase (K-S test, $D_{(m,n = 11)} = 1.00$, $p < 0.05$). The odds ratio was $\frac{97 \div 13}{56 \div 54}$ = 7.20 (95% CI: 3.61 – 14.33, $p < 0.05$). There was no statistically significant difference in the distributions of the RP and the GP for the “Upswing” phase (K-S test, $D_{(m,n = 11)} = 0.36$, $p > 0.05$). The odds ratio was $\frac{241 \div 144}{188 \div 197}$ = 1.75 (95% CI: 1.32 – 2.34, $p < 0.05$). There was no statistically significant difference in the distributions of the RP and the GP for the “Adjustment” phase (K-S test, $D_{(m = 11, n = 10)} = 0.30$, $p > 0.05$). The odds ratio was $\frac{45 \div 175}{52 \div 168}$ = 0.83 (95% CI: 0.53 – 1.31, $p > 0.05$). There was no statistically significant difference in the distributions of the RP and the GP for the “Downswing” phase (K-S test, $D_{(m,n = 11)} = 0.55$, $p > 0.05$). The odds ratio was $\frac{316 \div 124}{276 \div 164}$ = 1.51 (95% CI: 1.14 – 2.01, $p < 0.05$). There was no statistically significant difference in the distributions of the RP and the GP for the “Transition” phase (K-S test, $D_{(m,n = 11)} = 0.27$, $p > 0.05$). The odds ratio was $\frac{89 \div 296}{91 \div 294}$ = 0.97 (95% CI: 0.70 – 1.36, $p > 0.05$). There was a statistically significant difference in the distributions of the RP and the GP for the “Ending

Orientation" phase (K-S test, $D_{(m,n = 11)} = 0.73$, $p < 0.05$). The odds ratio was $\frac{94 \div 16}{57 \div 53} =$ 5.46 (95% CI: 2.86 – 10.45, $p < 0.05$). The intra-scorer reliability for the pounding SH pattern was Kappa = 0.55.

Discussion

The purpose of this study was to study the movement composition of two potential variations of two SH patterns, rubbing and pounding. This study used a universal language system, LMA, to study the kinematic and non-kinematic structure of the two SH patterns. By implementing LMA, I was able to develop an objective list of fine and gross motor limb movements as well as quantify the differences between the performances of two different SH patterns. Both rating scales, the RRS and PRS, and results from this study indicate that LMA is capable of providing in-depth descriptions of the subtle structural variations within the movements that create a behavioural expression such as rubbing a stone. The rating scales developed in this study can be used in future studies described at the end of the discussion section.

When compared through a series of odds ratios, the RP1 and RP2 were not statistically significantly different in terms of movement components in both the rubbing SH pattern and the pounding SH pattern. In other words, subjects were equally likely to perform the measures in the RRS and PRS when performing the RP1 and the RP2 of rubbing and pounding, respectively. This result indicates that the RP1 and the RP2 are performed in a similar manner despite their different temporal location in the SH sequence. The odds ratios comparing the RP1 and RP2 to the GP revealed that there were small differences in the odds of a subject performing more of the measures in the RRS and PRS, with the odds being higher when performing the RP1 or the RP2 (Chen et al., 2010; Cohen, 1988).

Once the RP1 and the RP2 were grouped as RP, regardless if they occurred before or after the GP, the subsequent series of K-S tests, comparing the distributions representing the occurrence of the measures within the RP and the GP, revealed that the "Starting Orientation" phase and the "Ending Orientation" phase were the only phases that were performed statistically significantly differently in each of the SH patterns. The odds ratios comparing the RP to the GP revealed that there were large differences in the odds of a subject performing more of the measures in the RRS and PRS, with the odds being higher when performing the RP than the GP (Chen et al., 2010; Cohen, 1988). However, these findings suggest that there are no distinct differences between the rougher/rigid and gentler/fluid performances of the rubbing and pounding SH patterns. There are three potential explanations for these findings. First, the way the subject orients themselves to the stones may influence the observers perception of the performance to be either rough (when the subject is orientating towards the stone) or gentle (when the subject orientates away form the stone). Second, it is possible that the measures in the "Starting Orientation" and "Ending Orientation" phases are sensitive enough to capture some of the subtle nuances in the performance of the rougher/rigid versus gentler/fluid performances by the subjects, but the subsequent measures are not sensitive enough. Third, the way the subject orients themselves to the stone may influence the quality of subsequent movements in ways that the other measures in the rating scales are not sensitive enough to capture.

The “Orientation” and the “Ending Orientation” phases of both SH patterns consist of two main measures, “Face orientated towards stone” and “Body orientated towards stone.” Both the ‘Orientation” and “Ending Orientation” phases reflect the subjects’ posture in relationship to the stone and the subsequent manipulation of the stone. The way the subjects orient themselves may be indicative of their intentions as well as the underlying cognitive mechanisms associated with each instance of SH (Emery, 2000; Langton et al., 2000; Perrett & Emery, 1994). Amongst other taxa, non-human primates often use the gaze direction and body orientation of conspecifics to interpret what they are attending to (for a review see Emery, 2000; Langton et al., 2000; Perrett & Emery, 1994). This study has shown that the main difference observed between the RP and the GP is the orientation of the subject, and potentially where the subject is attending to, while engaging in SH. Future analyses (Chapter Three) will investigate the role of visual attention on the performance of the rubbing SH pattern and the pounding SH pattern.

Whether or not the proximate or ultimate cause of engaging in SH is the same for both types of performances still needs to be investigated. For example, perhaps the subject is engaging in SH due to a playful motivation (Pellis et al., 2019), then briefly becomes distracted by an environmental stimulus, and thus performs the SH pattern in the gentler manner. Or perhaps the subject is engaging in SH due to a fidgeting related motivation and their attention is turned inwards in a state of spontaneous mind-wandering and this state of attention results in a gentler performance of the SH pattern (cf. Carriere et al., 2013; Seli et al., 2014).

The structure of a movement has the potential of unveiling the cause of the movement (Martin & Caro, 1985; Moran, 1985; Pellis & Pellis, 1998; Tinbergen, 1963). Typically in functional tasks, such as reaching to eat, healthy uninjured subjects (human or non-human), perform a series of movements (including inhibitory or stabilizing movements), in service of achieving their goal, or to fulfill the function of the behaviour, using the least energy possible (Foroud & Whishaw, 2006). Therefore, both obvious and subtle variations of a behaviour, such as the orientation of a subject, may indicate a variation in the execution of the underlying cognitive mechanisms (e.g., focus on the behavioural expression vs. an inward focus), or a different proximate or ultimate cause associated with that variation of the behaviour compared to the "typical" variation of the behaviour. This relationship between the structure of a behaviour and its function is a key component of the "design-feature argument" otherwise known as the structure-to-function framework (Martin & Caro, 1985; Moran, 1985).

Pelletier (2017) used Eshkol-Wachmann Movement Notation, another movement analysis, to demonstrate that there are structural variations present in the execution of the pounding SH pattern compared to nut pounding. The results presented by Pelletier (2017) indicate how variations of phenotypically similar behaviours may have different underlying motivational mechanisms. Building on the findings of Pelletier (2017), this study adds to the knowledge base of SH by identifying two different variations of *how* subjects posture themselves in relation to the stones. Future analyses will investigate *why* the subjects posture themselves in that specific way, beginning the exploration into the "function" aspect of the "structure-to-function" framework.

Given the preliminary results presented in this study, another pertinent question that needs to be asked is how we know when it is appropriate to categorize a performance, or even a behaviour, as a separate variation or as a different behavioural category (e.g., fidgeting, object play) (cf. Fentress, 1992; 2008). Rather than assume that each performance is completely unrelated to another, this study aims to propose an alternative view as building blocks for future analyses that may be able to address the categorization of the variations. Future studies will continue to use the RRS and PRS to assess the kinematic and non-kinematic structure of the rubbing and pounding SH patterns in various emotional (e.g., stress), motivational (e.g., using an edible item to perform the same SH patterns), and attentional (e.g., gaze direction) states. In this study, the RP and the GP were grouped in a binary manner for analytical purposes; however, it is entirely plausible that there is a gradient along which each individual SH pattern is executed. The gradient may reflect the subtle changing of an underlying mechanism (e.g., a shift of attention inwards, away from an external stimulus such as the stone).

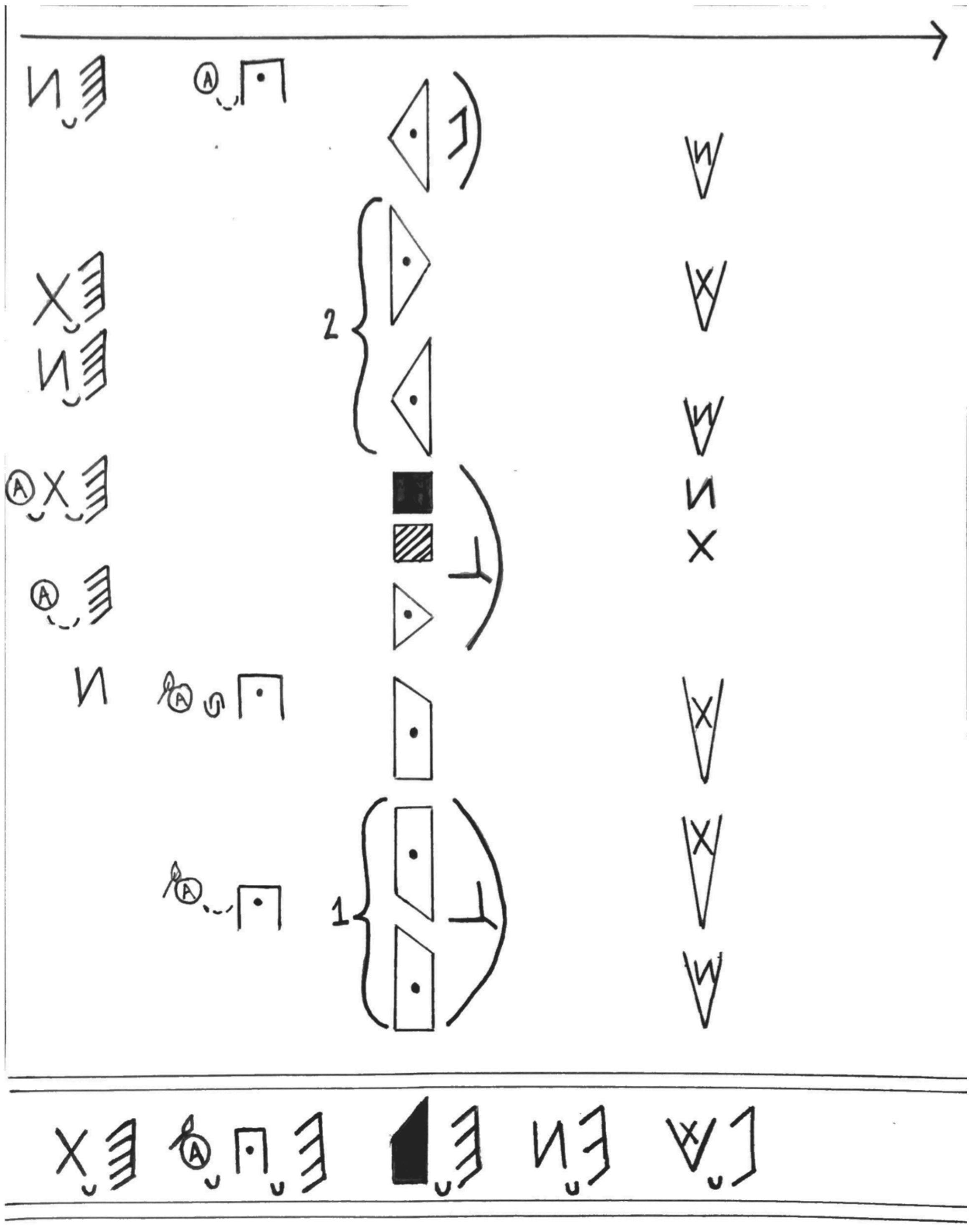
2
1

Figure 2.1. A portion of one Motif of two rubbing acts is provided as an example of Motif. For reference, each rubbing act is indicated by the numbered brackets. However, the brackets do not encompass the entire sequence of acts. The "Second Adjustment" and "Ending Orientation" phases of a rub are not in the bracketed section, these phases follow immediately after rubbing act 1 and 2 respectively. A Motif is read from the bottom up. The bottom portion encapsulated in the double bars represents the start of the action. The symbols in between the two sets of double bar lines represent the starting position of each limb notated in the Motif. From left to right: the fingers which are flexed, the palm of the hand which is touching the stone which is covered by a leaf (i.e., the circle with an A in it and a leaf on top), the hand, which is forward and down, the wrist which is extended, and the elbow which is approaching flexion. The single bar line at the top of the Motif indicates that the notation is continued on subsequent page. Duration is represented by the length of each symbol. The Rubbing Rating Scale was developed based on a series of Motifs derived from multiple rubbing acts performed by from multiple subjects (see Appendix B for the full list of measures and objective definitions).

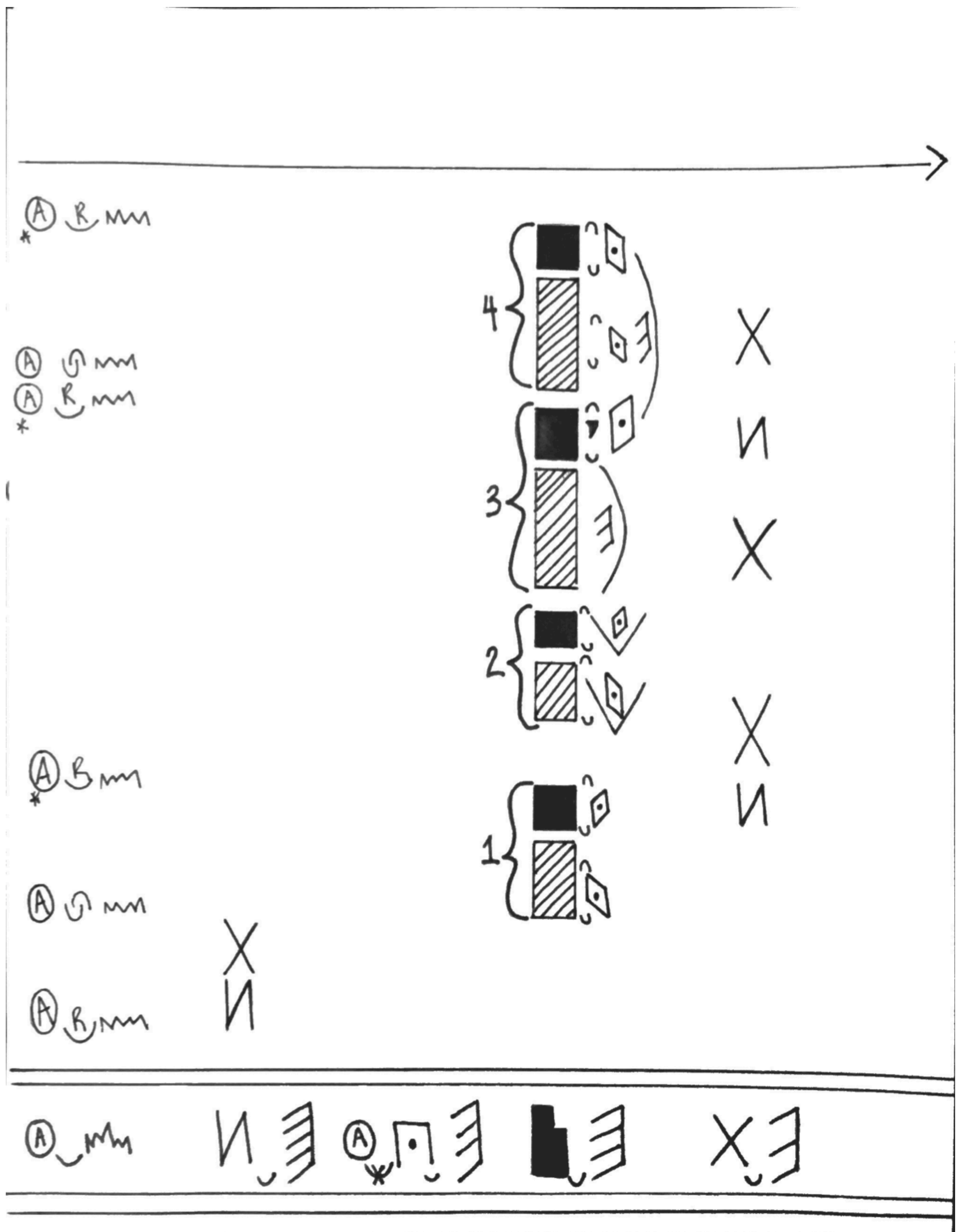
4
3
2
1

Figure 2.2. A portion of one Motif of four pounding acts is provided as an example of Motif. For reference, each pounding act is indicated by the numbered brackets. A Motif is read from the bottom up. The bottom portion encapsulated in the double bars represents the start of the notation. The symbols in between the two sets of double bar lines represent the starting position of each limb notated in the Motif. From left to right: the circle with an A in it connected to the squiggle represents the stone and the substrate, the fingers which are extended, the palm of the hand, which is touching the stone, the hand, which is forward and down, and the wrist which is flexed. The single bar line at the top of the Motif indicates that the notation is continued on a subsequent page. Duration is represented by the length of each symbol. The symbols encapsulated in brackets in the notation represent one act (i.e., a single pound). The Pounding Rating Scale was developed based on a series of Motifs derived from multiple pounding acts performed by multiple subjects (see Appendix B for the full list of measures and objective definitions).

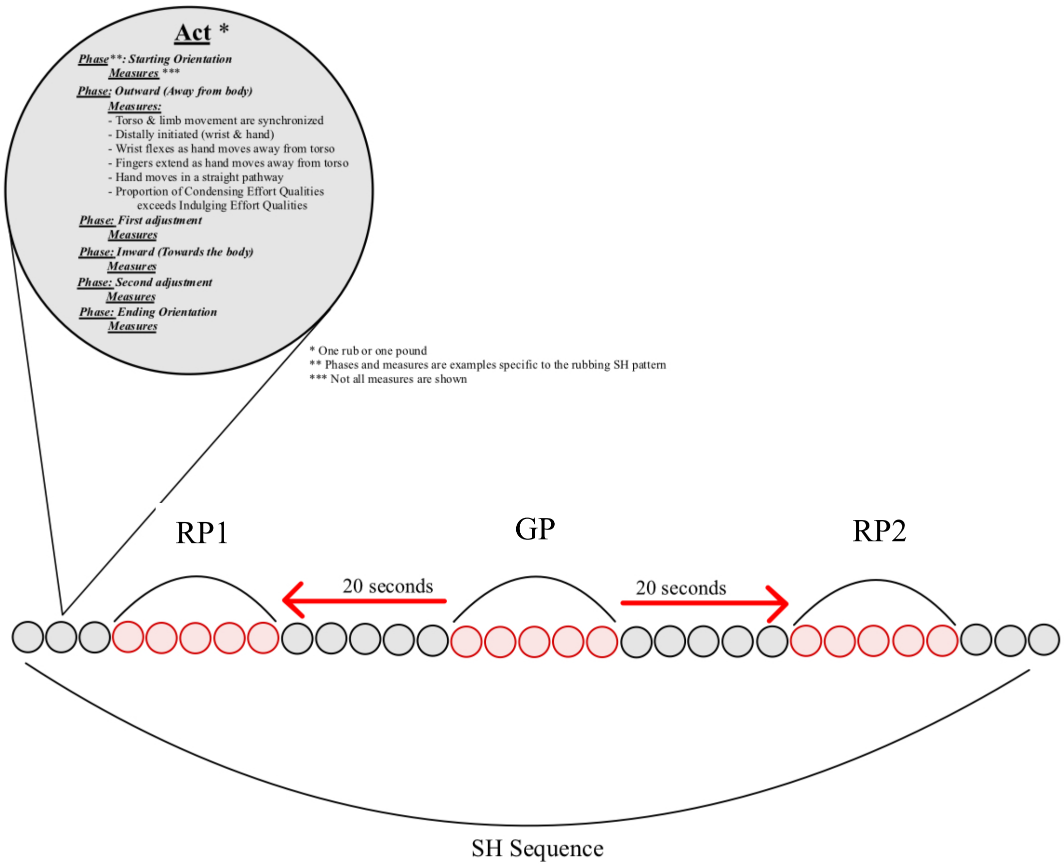

Figure 2.3. A visualization of a stone handling sequence is shown. Each circle represents one act. An act is one rub or one pound, consisting of the six phases of movement. A phase consists of one group of movements, referred to as measures, that are listed in sequential order, unless otherwise specified. The provided example of phases and measures in the highlighted act, pertains to the rubbing SH pattern. The acts in red represent the portion of the SH sequence selected for each variation. The red arrows labeled “20 seconds” represents the temporal criterion for selecting the portion of the SH sequence to represent each variation.

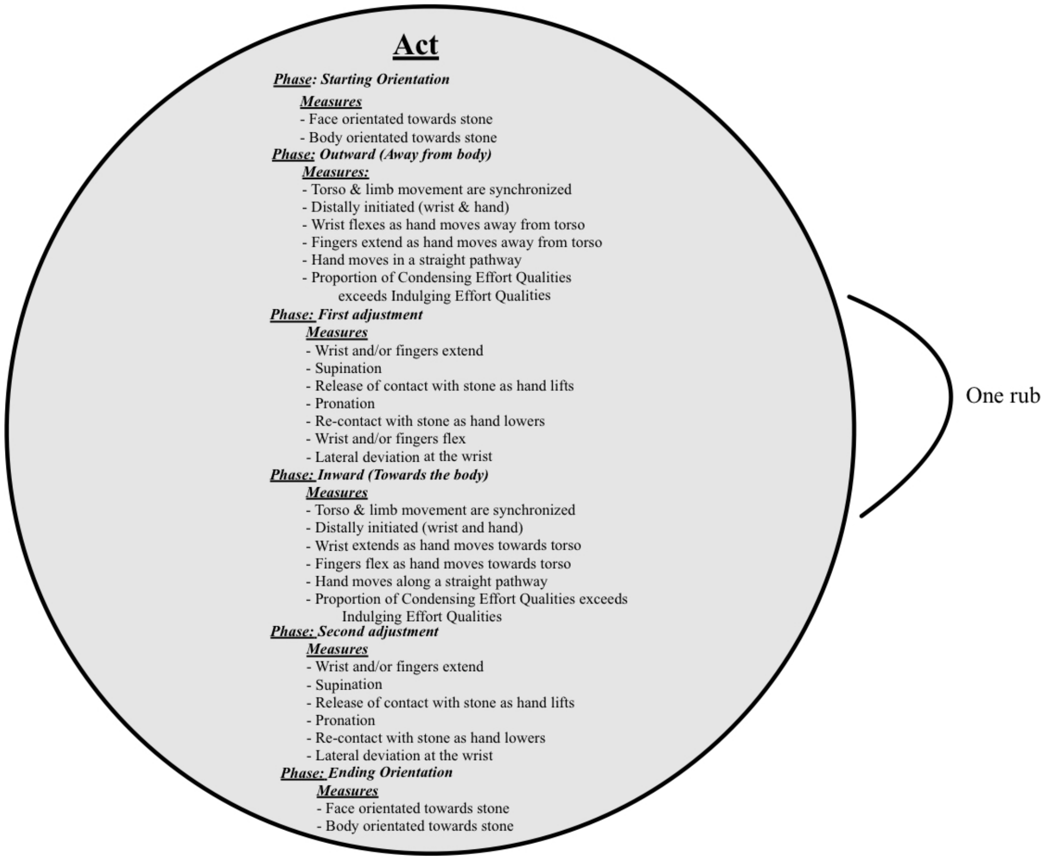

Figure 2.4. A visualization of a rubbing act consisting of each of the six phases and their corresponding measures is provided.

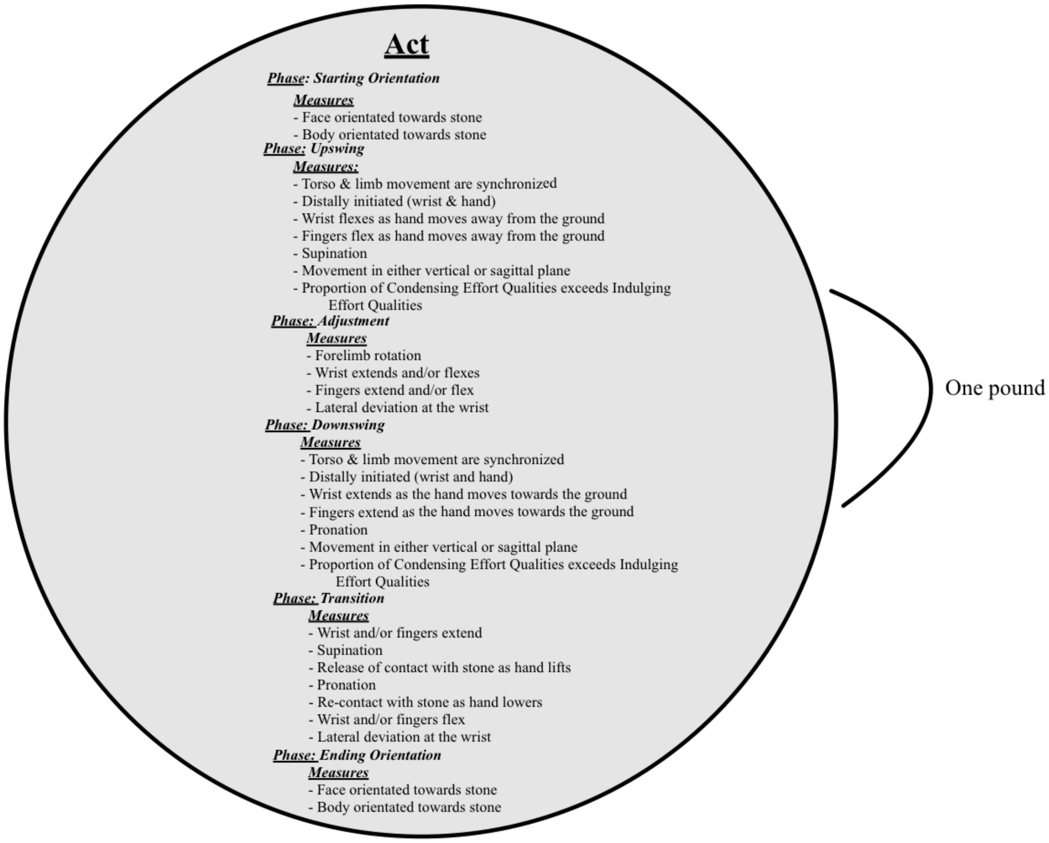

Figure 2.5. A visualization of a pounding act consisting of each of the six phases and their corresponding measures in each phase is provided.

Table 2.1. Study subjects' identity, sex and SH pattern notated for the Motifs

ID	Sex	SH Pattern
White Eyebrows	Male	Pounding
Zsolt	Male	Pounding
Splash	Male	Rubbing
Awkward Cami	Male	Rubbing
Pinocchio	Male	Rubbing

Table 2.2. Study subjects' identity and distribution of acts scored for the rubbing SH pattern for the RP1, GP, and RP2

ID	RP1	GP	RP2
Pinocchio	9	5	12
Awkward Cami	2	3	4
Splash	8	14	16

Table 2.3. Study subjects' identity and distribution of acts scored for the pounding SH pattern for the RP1, GP, and RP2

ID	RP1	GP	RP2
White Eyebrows	15	16	14
Zsolt	14	18	11
Zeus	7	3	3

Table 2.4. Study subjects' identity and distribution of acts scored for the rubbing SH pattern for the RP and the GP

ID	RP	GP
Zsolt	5	5
Obelix	7	7
Little Finger	7	7
Locke	5	5
Pinocchio	5	5
Splash	8	8
Lancelot	8	8

Table 2.5. Study subjects' identity and distribution of acts scored for the pounding SH pattern for the RP and GP

ID	RP	GP
Anvil	3	3
Danger	2	2
Little Finger	9	9
Ned	3	3
Temple Baggy	2	2
Temple	5	5
Zsolt	8	8
Logan	2	2
Mufy	2	2
White	16	16
Zeus	3	3

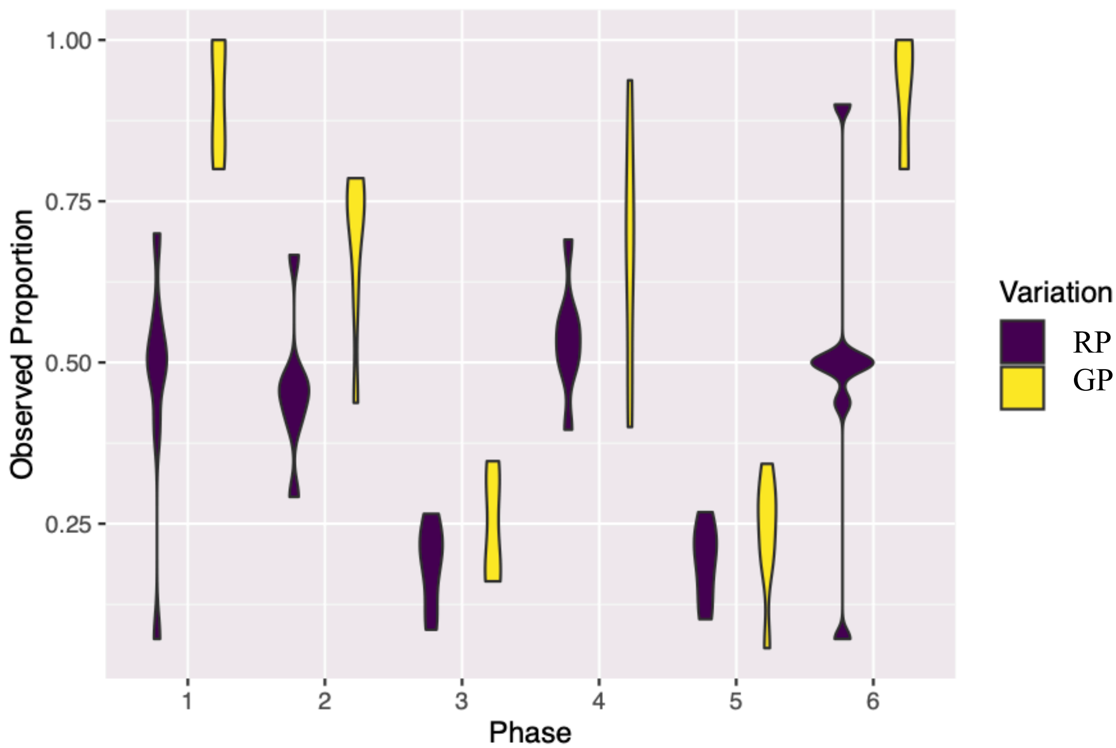

Figure 2.6. A violin plot featuring the different distributions of measures that occurred for each phase within the rubbing SH pattern. The height of each point (i.e., violin shape) shows the range of the observed proportion of occurrence while the width of each point shows the frequency of the observed proportion of occurrence. From left to right: 1 – Starting Orientation, 2 – Outward, 3 – First Adjustment, 4 – Inward, 5 – Second Adjustment, 6 – Ending Orientation. In the "Orientation" phase and the "Ending Orientation" phase, the distributions for the RP and the GP were statistically significantly different. For both phases, the corresponding measures occurred more often when the subjects were performing the RP.

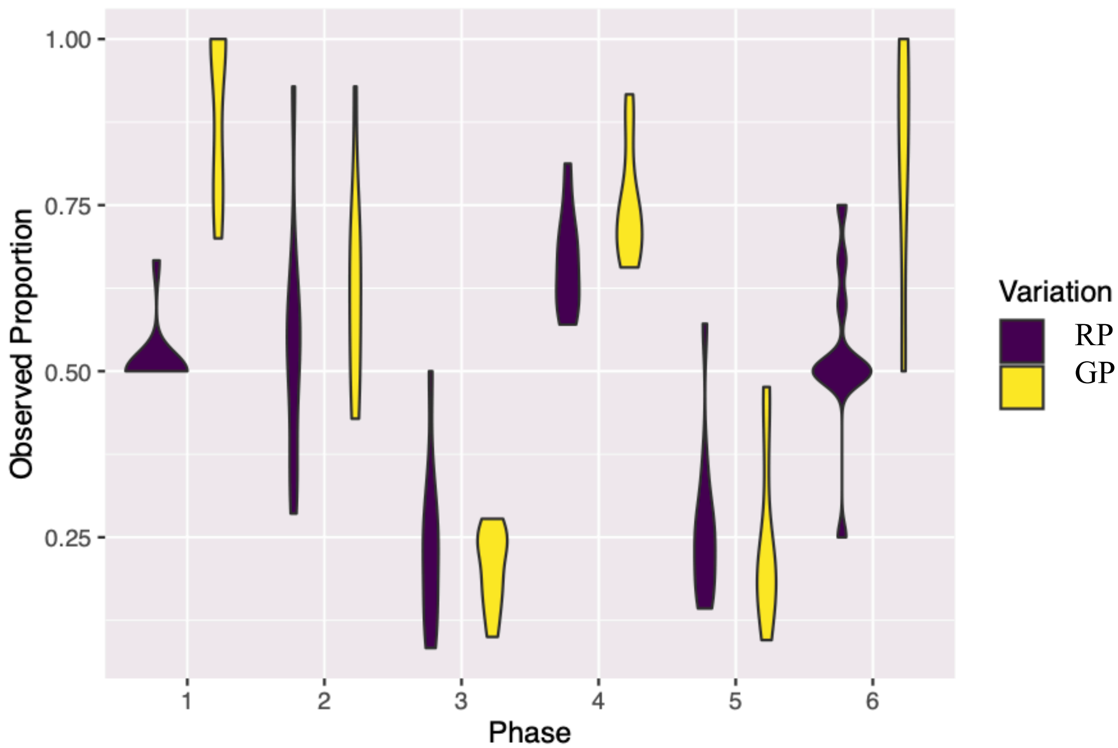

Figure 2.7. A violin plot featuring the different distributions of measures that occurred for each phase within the pounding SH pattern. The height of each point (i.e., violin shape) shows the range of the observed proportion of occurrence while the width of each point shows the frequency of the observed proportion of occurrence. From left to right: 1 – Starting Orientation, 2 – Upswing, 3- Adjustment, 4 – Downswing, 5 – Transition, 6 – Ending Orientation. In the "Orientation" phase and the "Ending Orientation" phase, the distributions for the RP and the GP were statistically significantly different. For both phases, the corresponding measures occurred more often when subjects were performing the RP.

CHAPTER THREE
The Role of Gaze Direction on the Structural Composition of Two Stone Handling Behaviour Patterns: A Structural Analysis of Rubbing and Pounding in Balinese Long-Tailed Macaques

Abstract

Stone handling (SH) is a repetitive, playful, object-directed behaviour performed by geladas and multiple species of macaques. Across species, there are approximately 40 SH behavioural patterns otherwise known as SH patterns. Overall, SH is a highly variable behavioural category. When handling the stones, an individual may perform the same SH pattern repeatedly or switch between SH patterns. The underlying attentional, emotional, and motivational states of SH remain unknown. The arbitrary, repetitive, and variable features observed in SH have also been observed when humans engage in fidgeting. Currently fidgeting is associated with wandering attention from the focal task and with stress. To further our understanding of the attentional processes associated with SH, this study draws on the current understanding of fidgeting to examine the role of gaze direction on the structural composition of two SH patterns, rubbing and pounding, in Balinese long-tailed macaques. I employed a movement analysis system, Eshkol-Wachmann Movement Notation, to assess if forehead direction is a suitable proxy for gaze direction. I then used two rating scales (namely, the Rubbing Rating Scale and Pounding Rating Scale) developed in previous work (Chapter Two) to quantify the structural composition of rubbing and pounding when the subject was looking at the stone and when they were looking away from the stone. The rating scales were developed using Laban Movement Analysis. The results from this study highlight the variability within an individual SH pattern that is dependent on the gaze direction. This variability primarily stems from the synchronization, or lack thereof, of the active limbs (i.e., the

fingers, hand, wrist, forearm, and upper arm manipulating the stone), and the torso. Additionally, movements possessed more rigidity and constraint during states in which the gaze direction was on the stone. The use of the two rating scales derived from a universal, and objective 'language' system, provides a strong foundation for future investigations on the role of attention in causally opaque and seemingly functionless object manipulation such as fidgeting.

Introduction

Since fidgets (i.e., small non-edible objects that can be squeezed, squished, pressed, pulled, spun, or chewed using the hands and mouth) have entered the market, the phenomenon of fidgeting has become more apparent in the media and the daily conversations of the public (da Câmara et al., 2018; Hulick, 2017). Researchers spanning the fields of education, occupational therapy, human-computer interactions, psychiatry, and clinical psychology have been investigating both *how* and *why* fidgeting occurs (Andrade, 2010; Belak et al., 2017; Carriere et al., 2013; da Câmara, et al., 2018; Graziano et al., 2018; Hansen et al., 2017; Karlesky & Isbister, 2016; Mathis, 2019). The behavioural category of fidgeting encompasses a diverse range of behaviours including self-directed (e.g., hair twirling), fine motor movements (e.g., tapping a finger on your desk) and object-directed manipulations (e.g., the repetitive and arbitrary clicking of a pen or the unfolding and re-shaping of a paper clip) (Mathis, 2019; Perrykkad & Hohwy, 2020; Reinecke et al., 2020). The range of documented fidgeting behaviours, such as those previously described, have resulted in a limited understanding of fidgeting as a behavioural category (Reinecke et al., 2020). However, despite the lack of information on fidgeting, this activity has been used as a measure of attention in studies investigating attentiveness and retention (Carriere et al., 2013; Farley et al., 2013; Lion-François et al., 2017). Fidgeting is also used as a diagnostic criterion for neurodevelopmental disorders including Attention-Deficit/Hyperactivity Disorder (ADHD) (American Psychiatric Association, 2013).

The diversity of behavioural expressions that are categorized as fidgeting have also been categorized as: displacement behaviours, stereotypic behaviours, akathisia, and psychomotor agitation (American Psychiatric Association, 2013; Barash, 1974; Sachdev & Kruk, 1996; Troisi, 2002). The lack of consensus on an objective definition of fidgeting is problematic as it prevents further understanding of the behavioural category and may cause problems when diagnosing children and adults with attentional disorders (Reinecke et al., 2020; Sayal et al., 2006). For example, Sayal et al. (2006) found that parents often described children as having behavioural and learning problems rather than hyperactivity (i.e., excessive motor activity or excessive fidgeting), thus preventing the proper diagnosis of their child (American Psychiatric Association, 2013). Similarly, da Câmara et al. (2018) found that parents had trouble identifying fidgeting behaviours in their children and often confused what the authors had dictated was fidgeting with play behaviours.

We now need to ask ourselves, does the behavioural category of fidgeting encompass multiple variations of one behaviour – fidgeting (e.g., leg swinging or pen clicking), or are multiple behaviours mis-categorized as fidgeting? When faced with behavioural categories, such as fidgeting and stereotypy, that share similarities in their observable, identifying characteristic(s) (e.g., repetition), and the cognitive processes(s) underlying the behaviour (e.g., attentional processes), the distinguishing line between behavioural categories becomes blurry (cf. Fentress, 2008). This study aims to utilize the current understanding of fidgeting (i.e., a repetitive yet variable and ubiquitous behaviour) to investigate another repetitive, variable, and ubiquitous behavioural category of non-instrumental object manipulation performed by non-human primates – stone handling (SH) (Cangiano & Palagi, 2020; Nahallage et al., 2016; Pelletier et al., 2017). While this study does not directly address the movement structure of behavioural expressions of fidgeting in humans, it aims to touch on the power of a systematic cross-species comparative approach by highlighting two ambiguous non-instrumental manipulative behavioural categories: fidgeting and SH (cf. Leca & Vasey, 2016). Cross-species comparative approaches can highlight the co-evolution and transformations (i.e., the changes a behaviour goes through over time due to phenotypic and genetic conditions) of behaviours over a period of time and between species along with their associated underlying processes (Martins, 1996).

SH is a category of repetitive, but not stereotypic, non-instrumental and playful manipulation of stones observed in groups of geladas (*Theropithecus gelada*), Japanese macaques (*Macaca fuscata*), rhesus macaques (*M. mulatta*), Taiwanese macaques (*M. cyclopsis*), and long-tailed macaques (*M. fascicularis*) (Cangiano & Palagi, 2020; Nahallage et al., 2016; Pelletier et al., 2017). The behavioural category of SH is composed of multiple distinct SH behavioural patterns, referred to as SH patterns, each being described as "a single, non-instrumental, stone-directed, specifically defined manipulative action" such as rubbing, pounding, rolling, or gathering (Pelletier, 2017, p. 26). SH patterns are performed during a SH bout, typically defined as a period of time in which an individual engages in SH with interruptions no longer than 120 seconds (Huffman, 1996). Within a given SH sequence, truncated from a SH bout, an individual may perform one SH pattern multiple times, or alternate between multiple SH patterns repeatedly; however, SH is not a stereotypic behavioural category due to variation in the execution of a SH pattern (Cenni et al., in press; cf. Mason, 1991). Variation(s) may be due to individual preference (e.g., one individual may choose to use both hands while another may choose to use one hand to manipulate the stone in similar ways), environmental context (e.g., individuals may manipulate the stone as a form of agonistic display, such as throwing the stone), and environmental constraints (e.g., stone availability, shape/texture of the supporting substrate) (Leca et al., 2008a, 2008b, 2010a, 2010b, Leca et al., 2008c; Nahallage & Huffman, 2008a). Additionally, it appears that the choice of SH pattern performed is up to the individual. It is unknown why an individual would choose to rub a stone rather than pound the same stone, making the selection of SH patterns an arbitrary decision (Cenni, in review; Pelletier et al., 2017). Finally, there are anecdotal observations of variations in an individual's concentration levels while they are engaged in SH (Chertoff, personal observation). At times it appears as if the same individual alternates between concentrating on the SH pattern(s) they are performing, and performing a less vigorous version of the same SH pattern(s), as if they became distracted by an environmental stimulus but continued to engage in SH (for a review on concentration, see Moran, 2012).

Beyond the previously described anecdotal observations in which the subject appeared to be "concentrating" on engaging in SH, there is no information on the role of attention in the performance of SH behaviour. Previous analyses demonstrated that within a single SH pattern (the rubbing and pounding SH patterns, respectively), there was little variation in the kinematic structure (i.e., spatial-temporal, body and environmental relationships) as the SH pattern was executed with the exception of the orientation of the individual to the stone (Chertoff, 2019; for descriptions of kinematic and non-kinematic structure see Foroud & Whishaw, 2006). The differences occurred in the "Orientation" phases of each pattern, indicating that the manner in which the subjects orient themselves towards the stone may be indicative of their intentions (i.e., an underlying cognitive mechanism) associated with those particular SH sequences as well as account for some performances appearing to be rougher or gentler (Emery, 2000; Langton et al., 2000).

The repetitive, arbitrary, and ambiguous characteristics of SH share a close resemblance with the previously described characteristics associated with fidgeting. Both behavioural categories contain the arbitrary selection of behavioural patterns (e.g., pounding or rubbing for the SH category, and tapping your foot or clicking your pen for the fidgeting category). Both behavioural categories also feature non-stereotypic repetitions and, finally, both categories may interact with attentional processes (Andrade, 2010; Chertoff, 2019; Farley et al., 2013; Graziano et al., 2018; Grodner, 2015; Seli et al., 2014). The likeness of fidgeting to SH renders SH an ideal model behavioural category to investigate the role of gaze direction on an arbitrary, repetitive, non-instrumental form of object manipulation. Gaze direction serves as a proxy to understand what a subject is visually attending to in their environment (for a review of the role of visual attention in non-human primates see Emery, 2000). Since fidgeting, and potentially SH, may interact with attentional processes, studying the role of gaze direction will provide a basis for future attention-based hypotheses (Andrade, 2010; Emery, 2000; Farley et al., 2013; Graziano et al., 2018; Grodner, 2015; Lion-François et al., 2017; Seli et al., 2014; cf. Faber et al., 2020).

While the function of SH remains unknown, this study employed the structure-to-function framework to explore the movement organization of two SH patterns: rubbing and pounding. The structure-to-function framework describes the kinematic and non-kinematic components of a behavioural expression to gain a better understanding of proximate effect(s) and ultimate function(s) of a behaviour (Martin & Caro, 1985; Moran, 1985). By notating the structure of two unique SH patterns, it is possible to identify motoric themes consistent across different variables, such as gaze direction (Pellis & Pellis, 1998). Identifying a motoric theme across different SH patterns may shed light on the underlying cognitive mechanisms (e.g., attention) and potential functions of SH (e.g., emotional regulation). Fentress (1977) described some potential relationships between underlying processes and their associated behavioural expressions as "tonic" in that the processes may extend beyond a singular behavioural expression and instead be reflected in a series of multiple behavioural expressions. In the context of this study, perhaps fidgeting and stereotypic movements share the same underlying process but are different behavioural expressions of that process(es).

This study uses the current literature on fidgeting to guide the interpretations of how gaze direction interacts with SH in Balinese long-tailed macaques (*Macaca fascicularis*). The main objective of this study is to further understand the structural variations within a SH pattern by examining the interaction between gaze direction and movement organization of the rubbing and pounding SH patterns. This study used a movement analysis system, Eshkol-Wachmann Movement Notation (EWMN), and the rating scales developed using Laban Movement Analysis (LMA). Both movement analyses are universal language systems that quantify the kinematic as well as non-kinematic features of a behavioural sequence. Both systems have been successfully used when studying non-human animals (Fagan et al., 1997; Golani, 1992; Pellis et al., 2019). In removing preconceived notions of a behaviour such as SH and implementing an objective movement analysis, it is possible to identify patterns (e.g., temporal patterns, fine motor movement patterns, gross motor movement patterns) correlated to different variables, such as gaze direction, that may have otherwise been missed. From there, it becomes possible to hypothesize about the function of the behaviour when the patterns (e.g., temporal patterns, fine motor movement patterns, gross motor movement patterns) are compared across variables (Fentress, 1992, 2008; Foroud & Pellis, 2021; Golani, 1992; Martin & Caro, 1985; Moran, 1985).

In the first part of this study, EWMN was used to determine whether forehead direction was a suitable proxy for gaze direction. Due to the pronounced brow bone of Balinese long-tailed macaques, it is difficult to consistently see the subject's gaze direction. Therefore, EWMN was used to evaluate whether forehead direction may be used in place of gaze direction when a subject was engaged in SH. In the second part of this study, following the implementation of EWMN, rating scales derived from LMA were used to score multiple SH sequences. Statistical analyses were done to compare sequences in which the subjects were looking at the stone and sequences in which the subjects were not looking at the stone (looking vs. not looking was determined using the forehead direction). Rubbing and pounding were the two SH patterns chosen due to their recognizable characteristics and because their basic kinematic composition differed from each other (e.g., the performance of rubbing remains in the horizontal plane whereas pounding is primarily performed in the vertical plane). Additionally, pounding was selected because previous research has used EWMN to compare the movement composition of stone pounding and nut pounding (Pelletier, 2017; Pellis et al., 2019).

Methods

Study site and population

Data for this study were collected at the Sacred Monkey Forest in Ubud, Bali, Indonesia. The Sacred Monkey Forest, or Ubud Monkey Forest, is a central location for a population of free-ranging and urban dwelling Balinese long-tailed macaques *(Macaca fascicularis fascicularis)*. Due to high volume of tourists and staff, the long-tailed macaques are habituated to human presence. The population studied consisted of approximately 900 individuals in six different groups with overlapping home ranges (Cambier, 2019). The monkeys were provisioned with fruits and vegetables at least three times a day by the staff of the Ubud Monkey Forest.

Data collection and study subjects

Video-recorded observations were collected between May and August in 2016, 2018, and 2019 by members of the Leca Lab. Data were collected using focal sampling and *ad libitum* sampling methods (Altmann, 1974). In this study, 25 individually identified subjects, both males and females were sampled in the following age classes: juvenile (aged 1-3 years), subadult (aged 3-6 years), young adult (aged 6-9), adult (aged 9 years and older) (Brotcorne et al., 2015). Subjects were members of three different groups, two of which had overlapping home ranges. Two different focal sampling protocols were used. In 2016, the focal sampling protocol dictated that during a focal follow, a subject was filmed for 15 minutes regardless of their activity. If the subject engaged in SH during the last two minutes of the observation, the observation was continued for an additional five minutes or until SH ceased and then continued for an additional two minutes after the subject was no longer handling the stones (cf. Huffman, 1996). In 2018, the focal sampling protocol dictated that during focal sampling, a subject was filmed for 30 minutes regardless of their activity. If the subject engaged in SH at the end of the 30-minute period, the focal follow was continued until the subject ceased SH. Focal samples were discarded if the focal subject was out of view (i.e., unable to be seen by the observer) for more than 10 minutes. *Ad libitum* sampling began when a subject was engaged in SH and continued for two minutes after the subject was no longer engaged in SH. When possible, focal subjects were filmed from the front or side so their face, torso, and limbs were visible, approximately 3-5 meters away from the observer. Data were collected using a Sony Full Handycam Camcorder.

Data analysis

This analysis was done in two parts. Part 1 was done using EWMN to assess whether forehead direction was a suitable proxy for gaze direction when the eyes of the subjects were not visible. Part 2 was done using two rating scales (namely, the Rubbing Rating Scale and the Pounding Rating Scale), developed using LMA to evaluate potential differences in the rubbing SH pattern and the pounding SH pattern, based on gaze direction.

Ethical statement

All data were collected using observational and non-invasive methodologies. This study was conducted in accordance with the Indonesian Ministry of Research and Technology (research permit #130/SIP/FRP/E5/Dit.KI/IV/2018), the Provincial Government of Bali, and the local district authorities. It was approved by the Institutional Animal Welfare Committee of the University of Lethbridge (Protocol #1906).

Study Part 1 – Is forehead direction a suitable proxy for gaze direction in Balinese long-tailed macaques?

3.1. Eshkol-Wachmann Movement Notation (EWMN)

EWMN was developed by Noa Eshkol and Abraham Wachmann[3]. At the time of its development, Eshkol was a proficient dancer and teacher. Prior to developing her own movement analysis, she studied under Rudolf Laban and Lisa Ullman, the creators of Laban Movement Analysis. Wachmann was a student of Eshkol as well as a student of architecture. Together, Eshkol and Wachmann developed EWMN to be a universal movement analysis. While EWMN was originally used in the realm of dance, the terminology is not dance-specific (Eshkol & Wachmann, 1958). The following subsections will provide information on EWMN.

3.1.1. Body

Both descriptions of the body and time are recorded simultaneously. The body is divided into limb segments, typically between two joints or a joint with a free moving end (Eshkol & Wachmann, 1958). For example, a limb segment may be the entire arm (commonly referred to as a limb in everyday conversation), the forearm, or the head. Often EWMN utilizes five common limbs with their segments: the left leg, right leg, the core body (i.e., the pelvis, torso, neck and head), the left arm, and the right arm. It is not necessary to utilize all five limbs as the researcher may decide to focus on one specifically unless the researcher is using the movement notation to inform themselves which limb segments to focus on for their studies. Just as Eshkol and Wachmann (1958) did not base EWMN solely on dance-related movements, EWMN did not depend on the

[3] For a complete timeline and biography on Noa Eshkol and Abraham Wachmann, see http://noaeshkol.org/timline/

preconceived notions or functions of the limb. In other words, simply because hands may be used for writing, this typical usage of the hands has no impact on the movement notation. As stated by Eshkol and Wachmann (1958), “If the end result of a movement is of no interest, the fulfilment of its ‘practical’ purpose has no relevance to the notation” (p. 5). Additionally, there is no hierarchy or specific importance placed on any one limb, nor does the shape of the limb play a role in the analysis. The removal of pre-conceived notions from the analysis allows the researcher to gain valuable information about the interactions of the limbs, their environment, and the underlying process of the behavioural sequence that may be clouded by the researcher’s previous views.

3.1.2. System of Reference

The System of Reference is the sphere, that surrounds each limb segment, combination of limb segments, or the entire body, depending on the researcher’s objective decision based on their question (Figure 3.1) (Eshkol & Wachmann, 1958). For limb segments, the center of the sphere is fixed on a joint (for example, imagine a sphere centered on your elbow and surrounding your forearm). Within each sphere, there is a horizontal plane and vertical plane. Remembering that each limb segment is seen as a straight line connected to an axis (i.e., the direction of movement from the joint, for example, a rotational axis), the observer decides which point on the sphere, within the horizontal plane is the absolute zero. Typically, from the absolute zero, there are eight positions in the horizontal plane stemming from the axis of the limb segment. These positions are separated by 45° and are numbered clockwise starting at 0 and ending at 8. However, 0 and 8 are equivalent positions. At each position on the horizontal plane, there is a perpendicular plane (i.e., the vertical plane). It is possible to reduce the degrees between each position or increase them depending on the research question. For example, a finer-grained analysis may benefit from 10 degrees (instead of 45 degrees) between each position, resulting in 20 positions (instead of 8). With each increase or decrease, the number of positions will change as will the number of intersecting vertical planes. At the beginning of every notation, it should be noted what scale the researcher has employed for their notation.

Using this System of Reference, it is possible to record any position of a limb. To do so, the vertical position is written above the horizontal position and then placed in brackets as follows: $\binom{1}{2}$ (Eshkol & Wachmann, 1958). Imagine that you are standing with your feet placed on the ground and hands along your side, if your upper right arm is the limb of focus then in the following position, $\binom{1}{2}$, your arm needs to rise until a 45° is formed between your upper arm and torso while your arm remains in line with your torso. As previously stated, any limb segment position and movements of each limb segment (i.e., the change from one position to another) may be recorded.

3.1.3. Types of Movement

There are three types of movement recorded in EWMN: planar, conical, and rotational movements (Figure 3.2) (Eshkol & Wachmann, 1958). Planar movements encompass movements that form a single plane either horizontally or vertically through their motion. For example, imagine again that you are standing with your feet placed on the ground and hands along your side. Keeping your elbow pinned at your side, bend your elbow until your forearm and hand are parallel to the ground. Now sweep your forearm and hand open as a door does while keeping your elbow tight against your side. This sweeping motion is a planar movement. Jumping jacks are another example of planar movement[4]. Rotational movements encompass movements in which the limb segment rotates on its own axis, either clockwise or counterclockwise, without changing its position in space. For example, imagine that you are turning a doorknob. In this example, your hand and forearm are rotating but are not moving to a different location in space until you release the doorknob. The third type of movement is conical; conical movements occur when the limb segment moves and creates a conical shape. For example, swinging a hula-hoop around your waist is a form of conical movement.

Scoring

Eight subjects, ranging in age from juvenile to adult of both sexes, were selected for this study (Table 3.1). Previous research has indicated that in many bipedal and quadrupedal organisms, such as macaques, the orientation of the body and head may be a reliable proxy for gaze direction as well as suitable indicator of where/what a subject is attending to when gaze direction is visible (for a review of the ethology, function and evolution of gaze direction, see Emery, 2000; Langton et al., 2000). Due to the pronounced brow bone of Balinese long-tailed macaques, it is difficult to see where the subject's eyes are pointed (i.e., gaze direction). To confirm that forehead direction is a suitable proxy for gaze direction in the study species, I used EWMN to test whether the direction of the subject's forehead was consistent with their gaze direction. Samples, obtained from the focal follow videos, were selected from three different contexts to have a representative sample of gaze direction. Contexts included: resting, manipulating an object while not looking at the object, and scratching. Within each context (e.g., resting), samples were selected from three times of day: morning (8:00 – 11:00 AM), midday

[4] http://noaeshkol.org/about-eshkol-wachman-movement-notation/basic-principals-of-ewmn/

(11:00 – 2:00 PM), and mid-/late afternoon (2:00 – 5:00 PM). Samples selected were the first cases seen in a focal follow in which gaze direction was clearly visible. It is important to note that not all samples were found for each subject leading to an un-even distribution of samples (Table 3.2). A sample consisted of series of video frames beginning with the first frame in which gaze direction was visible, and the last frame before gaze direction was no longer visible. The position of the forehead was notated at three points in the sample: the beginning (the first frame with visibility), the middle (the middle was determined by the length of the sample, for example, if the sample was 32 frames, the 16th sample frame was notated at the "middle"), and the end (the last frame with visibility). The position of gaze direction was notated at the same points as the forehead.

Statistical Analyses

These data were analysed using the binomial test. The binomial test uses a distribution consisting of the number of successes and failures to determine the probability of success. All notations were based on a 45° scale. Each sample notated per time of day for each context (e.g., "Morning – Resting" sample) was treated as one data point to maintain the independence of the data points. For the sample to be scored as a "success" at two points in the sample (e.g., the beginning and the middle), the two points needed to be aligned (i.e., the position of the forehead and the position of the gaze direction were aligned) (see Figure 3.3 for an example of aligned positions).

Study Part - Results

The proportion of aligned positions were significantly higher than expected by chance (Binomial test, $n_{success} = 47$, $n_{failures} = 6$, $p < 0.05$, two-tailed) (Table 3.2). Based on the binomial test, the direction of the forehead is a suitable proxy for gaze direction when a subject's gaze direction was not visible to the researcher. This finding is in line with previous research on the use of gaze direction, head direction, and body orientation for assessing where a subject is attending to (Emery, 2000; Langton et al., 2000; Perrett & Emery, 1994). It is important to note that certain samples were gathered from the same focal follow, for the same time of day, leading to limited amounts of dependency between samples. Additionally, because each coordinate is 45° apart, the precise angle of the gaze direction and forehead direction may have differed, resulting in random noise in the data.

Study Part 2 - Comparing the kinematic and non-kinematic structure of two SH patterns, rubbing and pounding, based on gaze direction

To examine the role of gaze direction on the movement composition of the rubbing and pounding SH patterns, this study used two rating scales developed in Chapter Two, the Rubbing Rating Scale (RRS) and the Pounding Rating Scale (PRS). The RRS and PRS were developed using Motifs, a short-hand notation used in LMA. The rating scales consisted of six sequential phases (e.g., starting orientation, outward, first adjustment, inward, second adjustment, ending orientation) (for a complete list of objective definitions of each phase and measure, see Appendix B). Each phase is comprised of a list of measures that describe discreet movement components that make up the phase (i.e., movements – ex. "Hand moves in a straight pathway") for both rubbing and pounding, respectively. The measures in each rating scale captured the structure of both SH patterns including the kinematic components (i.e., spatial-temporal, body, and environmental relationship) and the potentially supporting non-kinematic components (i.e., intensity, force, flow and rhythm) of a single "rub" or "pound" respective to the rating scale (i.e., an act). The rating scales provided a method for objectively quantifying the way the stones are manipulated under different conditions such as when the subject is looking at the stone and when they are not.

Scoring

For this part of the study, 17 adult male subjects were selected. For the rubbing SH pattern, eight adult males were selected and a total of 128 acts were scored (Table 3.3). For the pounding SH pattern, nine adult males were selected and a total of 135 acts were scored (Table 3.4). The subjects and acts were selected based on the following criteria: [1] subjects were adult males; [2] subjects had no new or obvious injuries that may impede movements involved with rubbing or pounding (e.g., a large open wound on their hand); [3] the stones must all be small enough that the subject was able to pick up the stone with one hand but not so small that the stone could not be seen in the subject's hand (e.g., a stone approximately between three and a half and ten centimeters in length); [4] the substrates (e.g., the forest floor or the pathway built for tourists) on which the subject was engaged in SH needed to be similar, meaning that there were no obvious factors that would impede typical movements (e.g., large cracks in the ground or large tree-roots emerging from the ground); and [5] all SH sequences were performed in a neutral state. A neutral state was defined as a state in which the subject was not exhibiting any displacement behaviours, aggressive, or submissive signals within one minute prior to performing the act of interest (for a review of typical displacement behaviours exhibited by non-human primates, see Troisi, 2002).

Once the acts were selected for the rubbing and pounding SH patterns, they were scored using the RRS and PRS respectively. All scoring was done by reviewing each act both frame-by-frame and in real time. If the measure occurred in the way it was defined (see Appendix B), then a 1 was scored. If the measure did not occur in the way it was defined, then a 0 was scored. Since the first measure of each rating scale was "Face orientated towards stone", this measure (validated in Part 1 of this study) was used to categorize acts in which the subject was looking at the stone and when they were not. The two resulting categories were "Looking" (LO) and "Not Looking" (NLO).

For both rubbing and pounding, an intra-scorer reliability test was conducted.

Statistical Analysis

All statistical analyses were performed for the rubbing SH pattern and pounding SH pattern separately. A series of odds ratios and two-sample Kolmogorov-Smirnov tests (K-S tests) were conducted to compare the LO and NLO categories. Since acts were categorized by LO and NLO during the scoring phase of this part of the analysis, the "Starting Orientation" and "Ending Orientation" phases were excluded.

An odds ratio is often used to compare the odds of occurrence of a behaviour based on a variable of interest. An odds ratio of 1 indicates that there was no effect due to the variable analysed, while an odds ratio less than or greater than 1 indicates that there was an effect due to the variable analysed. In this study, the number of times the subject scored a 1 was divided by the total number of times the subject scored a 0 as indicated by the rating scales. The odds ratio was then calculated by dividing the previously described values for the LO and NLO categories (ex.

$\frac{Number\ of\ times\ subject\ scored\ a\ 1\ \div number\ of\ times\ subject\ scored\ a\ 0\ in\ LO}{Number\ of\ times\ subject\ scored\ a\ 1\ \div number\ of\ times\ subject\ scored\ a\ 0\ in\ NLO}$). For this study, an odds ratio exceeding a value of 1 indicated that the subject was more likely to perform the measures in the rating scale when looking at the stone they were manipulating. An odds ratio of 1 indicated that there was no effect of gaze direction (i.e., subjects were equally likely to perform the measures) when the subjects were looking at the stone. An odds ratio lower than 1 indicated that the subject was less likely to perform the measures in the rating scale when looking at the stone they were manipulating. The 95% confidence interval was calculated as $e^{\ln(\mathrm{OR}) \pm 1.96\sqrt{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}+\frac{1}{d}}}$ where e is the mathematical constant for the natural log, ln is the natural log, and where *a* is the number of times subjects scored a 1 in the RP, *b* is the number of times subjects scored a 0 in the RP, *c* is the number of times subjects scored a 1 in the GP, and *d* is the number of times a subject scored a 0 in the GP. The z-score required to obtain a p-value was calculated as

$\ln(\mathrm{OR})/\sqrt{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}+\frac{1}{d}}$..

The two-sample K-S test is a non-parametric analysis used to compare two different distributions. To develop the distributions, data were filtered within subject, then by variation, and then by each phase of movement. Within each phase, the total number of times an individual scored a 1 for each measure was divided by the total number of times an individual *could* have scored a 1 for this measure. This resulted in a proportion representing the rate of occurrence of each measure, within each phase, for each subject. These proportions from each subject, created the distributions that were used in the series of K-S tests. All subjects were weighted equally. Only one value per subject was included in the distribution.

A Cohen's kappa coefficient was calculated to determine intra-scorer reliability. The closer the coefficient is to 1, the stronger the level of agreement is (Cohen, 1960). Significance levels were set at $\alpha = 0.05$. Analyses were done using R 3.6.2 (R Core Team, 2020; Wickham, 2016; Wickham et al., 2019), MedCalc Software[5], and manual calculations.

Study Part 2 - Results

Rubbing

There was no statistically significant difference between the distribution of the LO category and the distribution of the NLO category (K-S test, $D_{(m,\, n\, =\, 8)} = 0.25$, $p > 0.05$). The odds ratio was $\frac{861 \div 1089}{494 \div 884} = 1.41$ (95% CI: 1.68-2.29, $p < 0.05$ The results from the odds ratio may be a statistical artifact, specifically a Type I error due to how the data were aggregated across subjects rather than within subject. Due to the aggregation of data across subjects the data, the subjects are not weighted equally and there is pseudo-replication in the data set. In contrast, the K-S tests were conducted using distributions derived from proportions that accounted for differences in the number of acts scored per subject by using averages. Therefore, I primarily relied on the K-S tests when interpreting the results. However, as the two-sample K-S test only identifies *if* there is a significant difference between two distributions, odds ratios were reported because they identify the directionality of the difference between the two distributions.

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[5] MedCalc Software Ltd. Odds ratio calculator. https://www.medcalc.org/calc/odds_ratio.php

Additional K-S tests and odds ratios were calculated to compare the distributions of each major phase of a rub in the LO category and in the NLO category. There was no statistically significant difference in the distributions of the “Outward” phase ($D_{(m,\, n = 8)} = 0.63$, $p > 0.05$). The odds ratio was $\frac{311 \div 139}{170 \div 148} = 1.95$ (95% CI: 1.45-1.62, $p < 0.05$). There was no statistically significant difference in the distributions of the “First Adjustment” phase ($D_{(m,\, n = 8)} = 0.25$, $p > 0.05$). The odds ratio was $\frac{115 \div 410}{73 \div 298} = 1.15$ (95% CI: 0.82-1.59, $p > 0.05$). There was no statistically significant difference in the distributions of the “Inward” phase ($D_{(m,\, n = 8)} = 0.50$, $p > 0.05$). The odds ratio was $\frac{315 \div 135}{179 \div 139} = 1.81$ (95% CI: 1.34-2.44, $p < 0.05$). There was no statistically significant difference in the distributions of the “Second Adjustment” phase ($D_{(m,\, n = 8)} = 0.25$, $p > 0.05$). The odds ratio was $\frac{120 \div 405}{72 \div 299} = 1.23$ (95% CI: 0.89 – 1.71, $p > 0.05$) (Figure 3.4).

Final K-S tests and odds ratios were calculated to compare the distributions of each measure for the LO category and the NLO category. Of the 26 measures separately analysed using the K-S tests, two were statistically significantly different, both of which were in the “Outward” phase. There was a statistically significant difference in the distributions of the measure “Proportion of Condensing Effort Qualities exceeds Indulging qualities” ($D_{(m,\, n = 8)} = 0.75$, $p < 0.05$). The odds ratio was $\frac{69 \div 6}{31 \div 22} = 8.16$ (95% CI: 3.01-22.12, $p < 0.05$). There was a statistically significant difference in the distributions of the measure “Wrist flexes as hand moves away from torso” ($D_{(m,\, n = 8)} = 0.71$, $p < 0.05$). The odds ratio was $\frac{44 \div 31}{20 \div 33} = 2.34$ (95% CI: 1.14 – 4.82, $p < 0.05$) (Figure 3.5).

Pounding

There was no statistically significant difference between the distribution of the LO category and the distribution of the NLO category ($D_{(m,\, n\, =\, 9)} = 0.28$, $p > 0.05$). The odds ratio was $\frac{956 \div 944}{671 \div 889}$ = 1.27 (95% CI: 1.11-1.46, $p < 0.05$). The results from the odds ratio may be a statistical artifact, specifically a Type I error due to how the data were aggregated across subjects rather than within subject. Due to the aggregation of data across subjects the data, the subjects are not weighted equally and there is pseudo-replication in the data set. In contrast, the K-S tests were conducted using distributions derived from proportions that accounted for differences in the number of acts scored per subject by using averages. Therefore, I primarily relied on the K-S tests when interpreting the results. However, as the two-sample K-S test only identifies *if* there is a significant difference between two distributions, odds ratios were reported because they identify the directionality of the difference between the two distributions.

Additional odds ratios and K-S tests were calculated to compare the distributions of each major phase of a pound in the LO category and in the NLO category. There was a statistically significant difference in the distributions of the "Upswing" phase ($D_{(m,\, n\, =\, 9)} = 0.78$, $p < 0.05$). The odds ratio was $\frac{356 \div 169}{211 \div 209}$ = 2.09 (95% CI: 1.60- 2.72, $p < 0.05$. There was no statistically significant difference in the distributions of the "Adjustment" phase ($D_{(m,\, n\, =\, 9)} = 0.22$, $p > 0.05$). The odds ratio was $\frac{63 \div 237}{51 \div 189}$ = 0.94 (95% CI: 0.65- 1.49, $p > 0.05$). There was a statistically significant difference in the distributions of the "Downswing" phase ($D_{(m,\, n\, =\, 9)} = 0.78$, $p < 0.05$). The odds ratio was $\frac{426 \div 174}{304 \div 176}$ = 1.42 (95% CI: 1.10 – 1.83, $p < 0.05$). There was no statistically significant difference in the distributions of the "Transition" phase ($D_{(m, n = 9)} = 0.22$, $p > 0.05$). The odds ratio was $\frac{111 \div 414}{105 \div 315} = 0.80$ (95% CI: 0.59 – 1.09, $p > 0.05$) (Figure 3.6).

Final K-S tests and odds ratios were calculated to compare the distributions of each measure for the LO category and NLO category. Of the 26 measures separately analysed using the K-S tests, two were statistically significantly different. There was a statistically significant difference in the distributions for the measure "Torso & limb movement are synchronized" in the "Upswing" phase ($D_{(m, n = 9)} = 0.75$, $p < 0.05$). The odds ratio was $\frac{52 \div 23}{23 \div 37} = 3.64$ (95% CI: 1.78 – 7.44, $p < 0.05$) (Figure 3.7). There was a statistically significant difference in the distributions for the measure "Proportion of Condensing Effort Qualities exceeds Indulging Effort Qualities" in the "Downswing" phase ($D_{(m, n = 9)} = 0.67$, $p < 0.05$). The odds ratio was $\frac{72 \div 3}{49 \div 11} = 5.39$ (95% CI: 1.43 – 20.31, $p < 0.05$) (Figure 3.8).

Discussion

I used two rating scales, the RRS and PRS, to study the way the kinematic and non-kinematic structure of two SH patterns differed when the subjects were looking at the stones they were manipulating, and when they were not looking at the handled stones. The first part of this study validated the use of the direction of the forehead as a proxy for gaze direction for Balinese long-tailed macaques (see Emery, 2000; Langton et al., 2000; Perrett & Emery, 1994). Future studies may rely on this proxy when gaze direction is not available. The second part of this study revealed the correlation between gaze direction and the movement structure of both the rubbing and pounding SH patterns. Additionally, the structural variations closely mirrored one another in both the rubbing and pounding SH patterns. This suggests that gaze direction may play the same role during the performance of SH regardless of the SH pattern (e.g., rubbing or pounding) being performed.

In the rubbing SH pattern, the kinematic structure and non-kinematic structure differed depending on gaze direction. As the subject moved their hand away from their body while grasping the stone in the "Outward" phase, the wrist flexed. This fine motor movement occurred significantly more when the subject was looking at the stone. The odds ratio revealed that there were small to medium differences in the odds that a subject's wrist would flex as they moved the stone away from their body when they were looking at the stone compared to when they were not, with the odds of the former being higher than the latter (cf. Chen et al., 2010; Cohen, 1988). Physically, as the hand moves away from the body, it would be more difficult for the wrist to remain extended because the hand and arm are elongating during the outward movement. This result may be due to the subjects extending their arm farther when they are looking at the stone. This hypothesis will be tested in future studies.

In the pounding SH pattern, there was also a correlation between gaze direction and movement structure. When the subjects were looking at the stone they were manipulating, their torso and limb movements were synchronized with one another during the "Upswing" phase. The odds ratio revealed that there were medium differences in the odds that the subject's torso and limb movements were synchronized when they were looking at the stone compared to when they were not, with the odds of the former being higher than the latter (cf. Chen et al., 2010; Cohen, 1988). Physically, the torso provides support for the movement of the limb as the subject grasps and lifts the stone off the ground. The support from the torso aids in the accuracy in the lift while supporting the exertion of force necessary to lift the stone up. This result may be due to the subjects' intentions, or preparation, to strike the stone against the ground in a precise manner appearing more constrained than when the subjects were not looking towards the stone or ground (cf. Pelletier, 2017).

During the execution of both SH patterns, the subjects performed the patterns with significantly more Condensing Effort Qualities than Indulging Effort Qualities when they were looking at the stone compared to when their gaze was not on the stone. However, in the rubbing SH pattern, this measure occurred more in the "Outward" phase whereas in the pounding SH pattern, this measure occurred more in the "Downswing" phase. In both the rubbing and the pounding SH patterns, the odds ratio revealed that there were large differences in the odds that the SH pattern was performed with a higher proportion of Condensing Effort Qualities than Indulging Effort Qualities when the subject was looking at the stone compared to when they were not, with the odds of the former being higher than the latter, irrespective of the phase in which this measure occurred (cf. Chen et al., 2010; Cohen, 1988). Effort Qualities are not a reflection of the active or passive engagement of the subject, but rather encompass changes in exertion of energy throughout a movement (Bartenieff & Lewis, 1980; Foroud & Whishaw, 2006). Most Effort Qualities are non-kinematic qualities of movement, and all range from Indulging (a release of intensity) to Condensing (increasing intensity). Condensing Effort Qualities include Strong Weight Effort (an increase in the exertion of force), Bound Flow Effort (an increase in control and restraint), Quick Time (the acceleration of a movement), and Direct Space (the body is focused on something specific). Since the subjects were using more Condensing Effort Qualities than Indulging Effort Qualities when looking at the stone they were manipulating, we can start to identify which elements of movement composition of the two SH patterns are relevant, or related to, the potential effect(s) or function(s) of the behaviour based on gaze direction. For example, Condensing Efforts may involve more constrained movements throughout the whole execution of the pattern (Bartenieff & Lewis, 1980). Therefore, the use of Condensing Efforts may indicate that the subjects were focused on, or attending to, moving the stone towards a specific spot in relation to the ground to fulfill the purpose of the movement (cf. Pelletier, 2017). Based on this result, we can begin to hypothesize about the role of constraint (e.g., Strong Weight, an increase in the exertion of force, Bound Flow, an increase in control and restraint, Quick time, the acceleration of a movement, Direct Space, the body is focused on something specific) (Bartenieff & Lewis, 1980) during the execution of the rubbing and pounding SH patterns when subjects are looking at the stone they are manipulating.

When the subjects were not looking at the stone, they used less Condensing Effort Qualities compared to when they were looking at the stone. This result lends itself to three potential hypotheses. First, the "Coordination" hypothesis holds that when the subjects were not looking at the stone, they did not receive the same visual feedback from their hand manipulating the stone, thereby changing the way they handle the stone. Primates use eye gaze to guide where and how they will grasp an object as well as plan their motor movements (Johansson et al., 2001). Visual feedback during object manipulation alters the kinematics and accuracy of the hand movements in both humans and non-human primates (Connolly & Goodale, 1999; Prablanc et al., 1979; see

Crawford et al., 2004). Future studies will examine the role of Condensing Effort Qualities on the relationship between reach-and-grip accuracy and gaze direction.

Second, the "Distraction" hypothesis holds that when the subjects were not looking at the stone, they were still manipulating the stone to fulfill the same utility (e.g., play); however, they became distracted by an environmental stimulus and had not stopped moving their hand yet. This hypothesis relates closely to the first hypothesis. *Why* the subject is looking away from the stone may influence the manner in which they manipulate the stone, but the proximate or ultimate cause of the behaviour is consistent even when the subject is no longer looking at the stone. Third, the "Fidgeting" hypothesis continues to build on the first two hypotheses but addresses an entirely different proximate cause for engaging in SH when the subjects are not looking at the stone. When the subjects were not looking at the stone, they might perform the movement due to a different attentional state (e.g., mind-wandering), motivational state (e.g., play), or emotional state (e.g., stress).

Since gaze direction informs conspecifics about where a subject is attending to, we can also begin to hypothesize that [1] the subjects are no longer visually attending to the stone, and [2] the subjects may no longer be attending to their own performance (i.e., the execution of the movements involved in each SH pattern) or engagement (i.e., the motivation for performing the SH pattern) in SH (cf. Emery, 2000). If the subjects are no longer attending to their own engagement in SH, they may be attending to another environmental stimuli, such as a tourist walking by (i.e., the "Distraction" hypothesis), or they may be turning their attention inward in a state of mind-wandering (i.e., the "Fidgeting" hypothesis) (Smallwood & Schooler, 2006). While these observations and potential hypotheses do not yet directly inform about the proximate effect(s) or ultimate function(s) of SH, they allow us to identify the motoric patterns correlated with gaze direction which is the first step (Pellis & Pellis, 1998).

It is important to note that the interpretation of these variations present in both the rubbing and pounding SH patterns are context-dependent. The way an individual moves their limbs in relation to the rest of their body and their environment, both kinematically and non-kinematically, depends on the context in which they are moving (Fagen et al., 1997; Fentress, 1992, 2009). For example, while pounding a nut and pounding a stone may look very similar, the body moves in a way to maximize the effort necessary to execute the function (i.e., cracking a nut to eat the edible portion inside vs. object play) (Pelletier, 2017; Pellis et al., 2019; cf. Foroud & Whishaw, 2006). This was demonstrated in a previous study conducted by Pelletier (2017), who used EWMN to evaluate the manner in which a nut was pounded and a stone was pounded by adult male macaques. When pounding a nut, subjects raised the stone higher and swung the stone up and down faster compared to pounding a stone. Additionally, when pounding a nut, the subject's gaze direction was pointed towards the ground significantly more than when they were pounding a stone. Pelletier (2017) proposed that these differences were due to the functional constraint of nut pounding (i.e., extracting the edible portion of the nut). Again, the context in which a behavioural expression occurs is related to the way the subjects execute the behaviour. Furthermore, the context may directly relate to the function of the behaviour (e.g., foraging motivation) which in turn, influences the structural composition of the behavioural expression (Fagen et al., 1997; Fentress, 1992, 2009).

In the introduction of this chapter, I stated that this study aimed to touch on the power of a cross-species comparison. A cross-species comparison can help us to understand the co-evolution of a behaviour and how the behaviour has changed over time (Martins, 1996). At this point, this study considered a cross-species comparison by using the behavioural category of fidgeting, performed by humans, as a lens for the investigation of SH in Balinese long-tailed macaques. Future studies will further the goal of a cross-species comparison by using LMA to analyse object-manipulation performed by children in both playful contexts and contexts in which fidgeting is more likely to occur (e.g., during a group reading session). Once there is a baseline depicting the movement composition of object play and object-directed fidgeting in humans, I can compare any potential motoric themes to those that were present in the rubbing and pounding stone handling patterns presented in this study. Additionally, mind-wandering has been studied in relation to gaze characteristics such as, fixation (i.e., "a period of time when the eyes remain relatively still") frequency, duration, and dispersion, and saccades (i.e., "the eyes shift from location to location") (Faber et al., 2020, p. 1202). Future studies will implement these more specific gaze-related measures for both human and non-human orientated studies.

This study employed the "structure-to-function" framework to describe the interactions between the structure (i.e., the kinematic and non-kinematic components) of a behaviour and its possible proximate effect(s) and ultimate function(s) (Martin & Caro, 1985; Moran, 1985). By implementing the RRS and PRS, I was able to objectively quantify the differences in the structure of the rubbing SH pattern and the pounding SH pattern based on gaze direction. While I did not attempt to evaluate the potential effect(s) or function(s) of SH, this study used the principles of the “structure-to-function” framework to interpret the correlation between gaze direction and the motor composition of two SH patterns. Objectively describing the role of gaze direction in the expression of SH lays the foundation to study the role of attentional processes in the performance of SH.

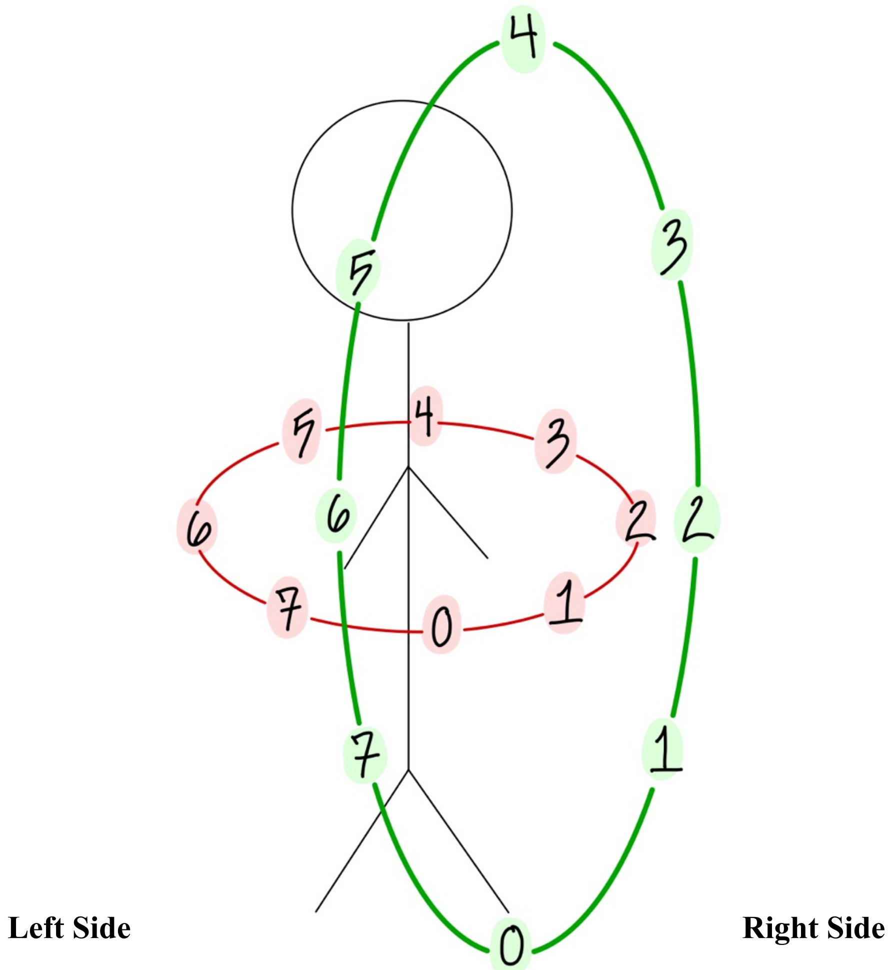

Figure 3.1. A simplified drawing of the primary horizontal and vertical planes of the Eshkol-Wachmann Movement Notation (EWMN) System of Reference. The red numbers represent the coordinates of the horizontal plane. The green numbers represent the coordinates of the vertical plane.

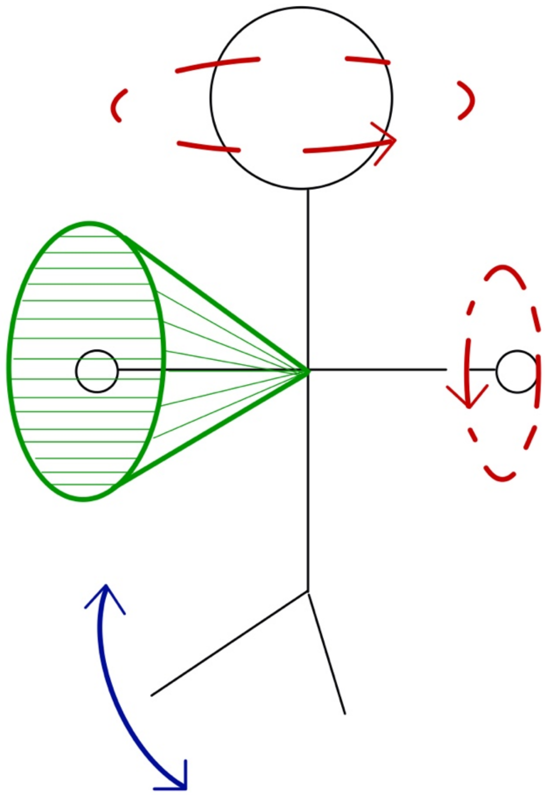

Figure 3.2. A simplified drawing of the three types of movement notated in Eshkol-Wachmann Movement Notation (EWMN). The blue line represents planar movements. The red lines represent rotational movements (rotatory movements do not trace lines in space; they make a dot in space; this drawing is an example, not to be confused with conical movements). The green lines represent conical movements.

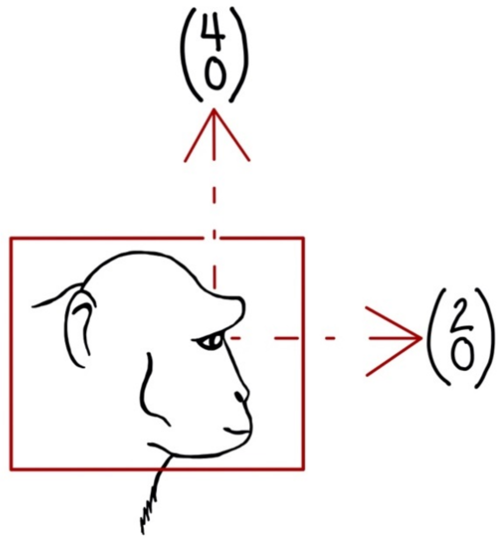

Figure 3.3. Aligned coordinates. The coordinates for the position of the forehead and the coordinates of the gaze direction are aligned meaning that the direction of the forehead and the eyes are the same and the coordinates reflect that.

Table 3.1. Identity, sex, and age classes of each subject included in Part 1

ID	Sex	Age Class
Upie	Male	Juvenile
Talung	Female	Juvenile
David	Male	Juvenile
MJ	Male	Subadult
Scarface	Male	Subadult
Mary	Female	Young Adult
Perry	Male	Young Adult
Lauren	Female	Adult

Table 3.2. Distribution of samples scored, number of successes, and number of failures per subject included in Part 1. The maximum number of samples per subject is 9 (3 times of day × 3 contexts = 9 potential samples).

Subject	Number of Samples	Success	Failures
Upie	8	5	3
Talung	7	7	0
David	6	5	1
MJ	9	8	1
Scarface	6	6	0
Mary	4	4	0
Perry	7	6	1
Lauren	6	6	0

Table 3.3. Study subjects' identity and distribution of acts scored for the rubbing SH pattern for the Looking and Not Looking categories.

ID	Looking	Not Looking
Obelix	7	4
DawsonT	4	4
Little Finger	8	7
Danger	9	7
Temple Baggy	7	7
Pinocchio	12	3
Lancelot	6	7
Splash	22	14

Table 3.4. Study subjects' identity and distribution of acts scored for the pounding SH pattern for the Looking and Not Looking categories.

ID	Looking	Not Looking
Anvil	2	4
Little Finger	9	7
Ned	3	6
Temple Baggy	3	2
Temple	6	6
Zsolt	18	9
Mufy	4	3
White Eyebrows	20	18
Zeus	10	5

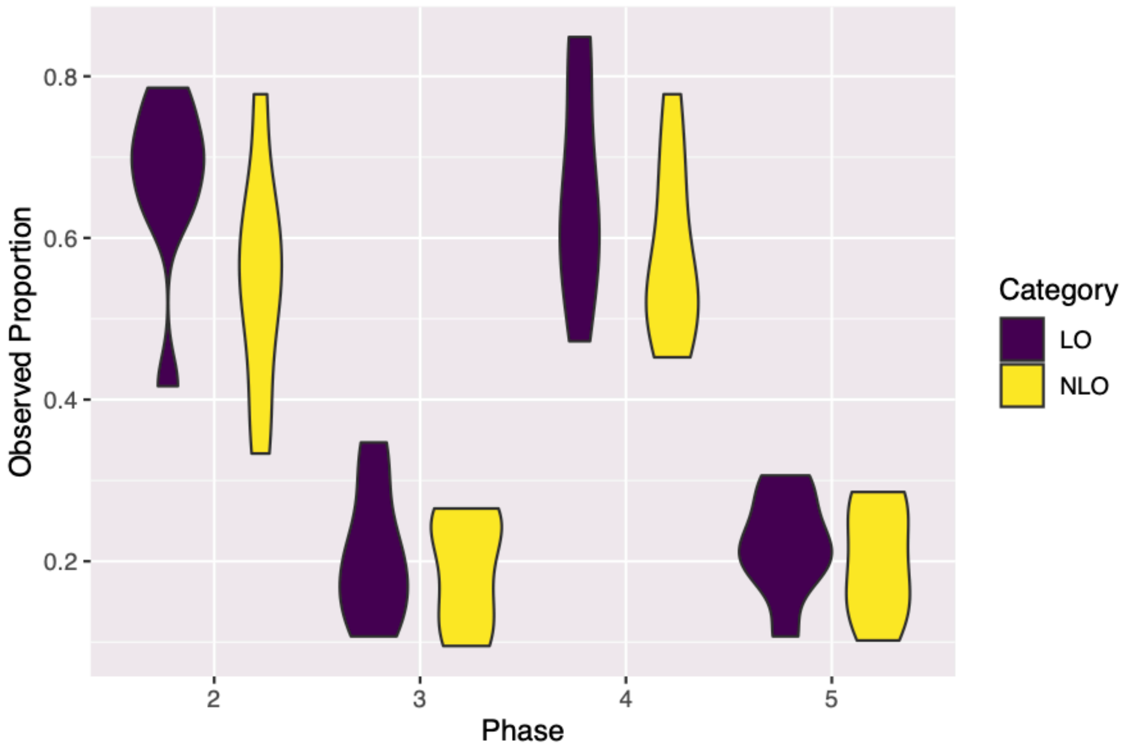

Figure 3.4. A violin plot featuring the different distributions of measures that occurred for each phase within the rubbing SH pattern. The height of each point (i.e., violin shape) indicates the range of the observed proportion of occurrence while the width of each point indicates the frequency of the observed proportion of occurrence. From left to right: 2 – Outward, 3 – First Adjustment, 4 – Inward, 5 – Second Adjustment. The distributions for the Looking and Not Looking categories were not statistically different for any of the phases.

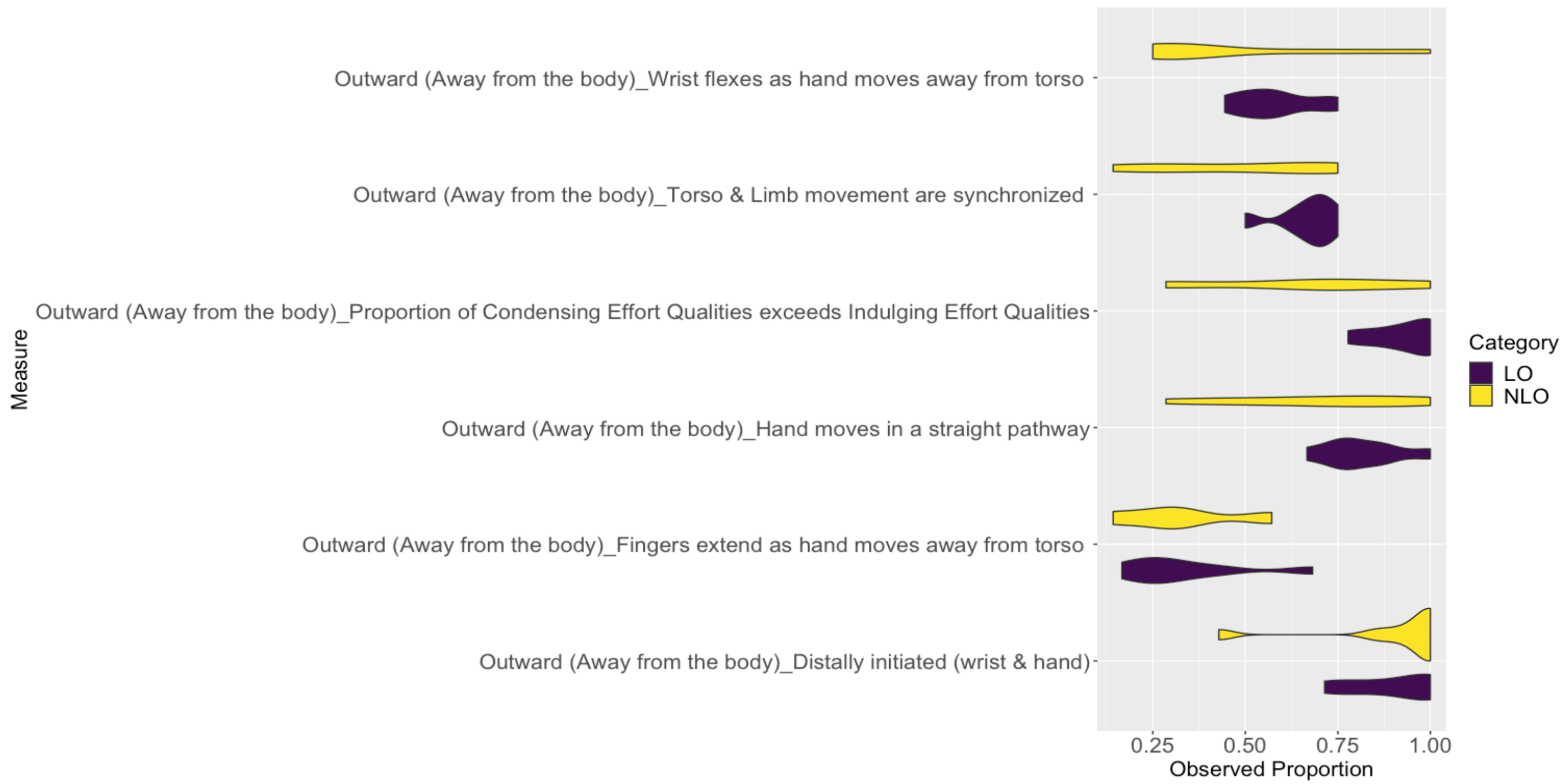

Figure 3.5. A violin plot featuring the different distribution of measures that occurred for each phase within the rubbing SH pattern. The height of each point (i.e., violin shape) shows the range of the observed proportion of occurrence, while the width of each point shows the frequency of the observed proportion of occurrence. The distributions for the Looking and Not Looking categories are statistically significantly different for the measure "Proportion of Condensing Effort Qualities exceeds Indulging Effort Qualities." The subjects were more likely to use Condensing Effort Qualities during the "Outward" phase when they were looking at the stone. Additionally, the distributions for the Looking and Not Looking categories are statistically significantly different for the measure "Wrist flexes as hand moves away from torso." The subjects were more likely to flex the hand away from the torso during the "Outward" phase when they were looking at the stone.

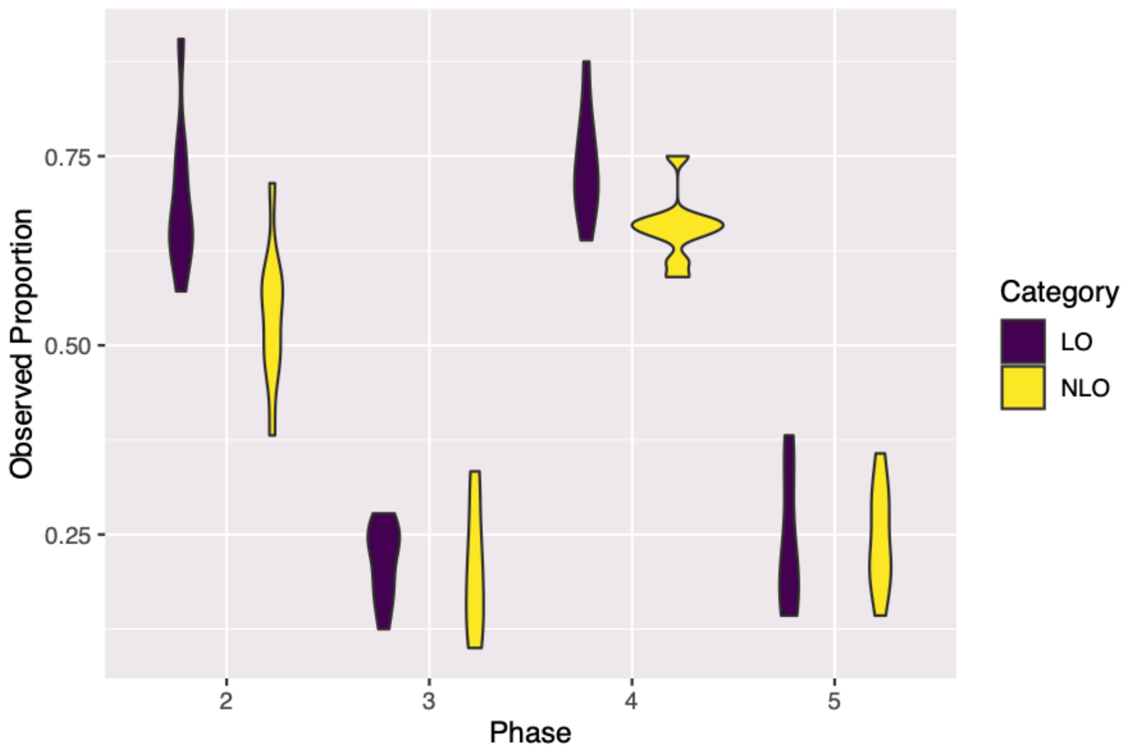

Figure 3.6. A violin plot featuring the different distributions of measures that occurred for each phase within the pounding SH pattern are shown. The height of each point (i.e., violin shape) shows the range of the observed proportion of occurrence, while the width of each point shows the frequency of the observed proportion of occurrence. From left to right: 2 – Upswing, 3 – Adjustment, 4 – Downswing, 5 – Transition. In the "Upswing" phase and "Downswing" phase, the distributions for the Looking and Not Looking categories are statistically significantly different. For both phases, the corresponding measures occurred more often when subjects were looking at the stone.

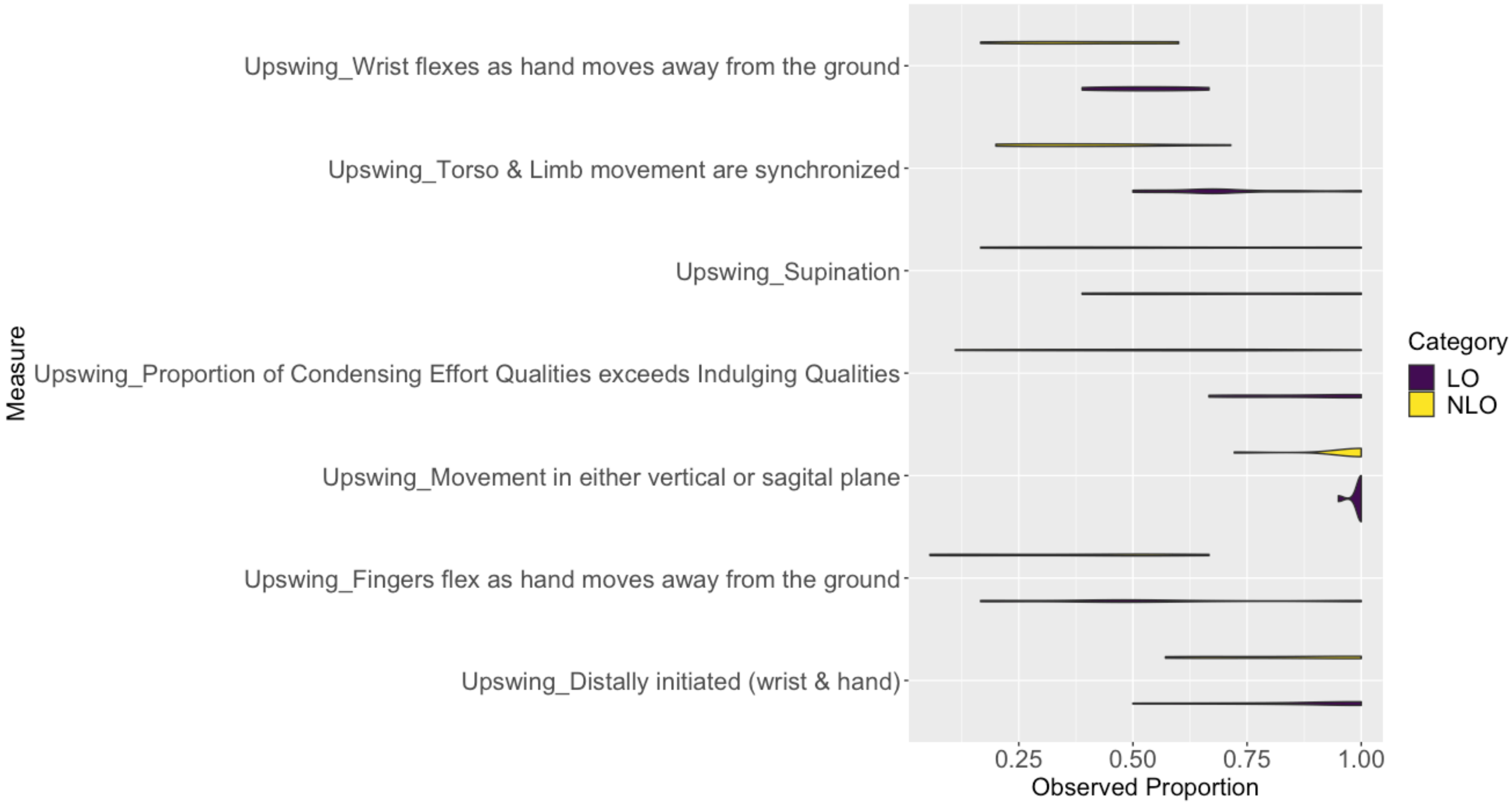

Figure 3.7. A violin plot featuring the different distribution of measures that occurred for each measure in the "Upswing" phase of the pounding SH pattern is shown. The height of each point (i.e., violin shape) shows the range of the observed proportion of the occurrence, while the width of each point shows the frequency of the observed proportion of occurrence. In the "Torso and limb movement are synchronized measure", the distributions for the Looking and Not Looking categories are statistically significantly different. The subjects were more likely to perform this measure, in the "Upswing" phase, when they were looking at the stone.

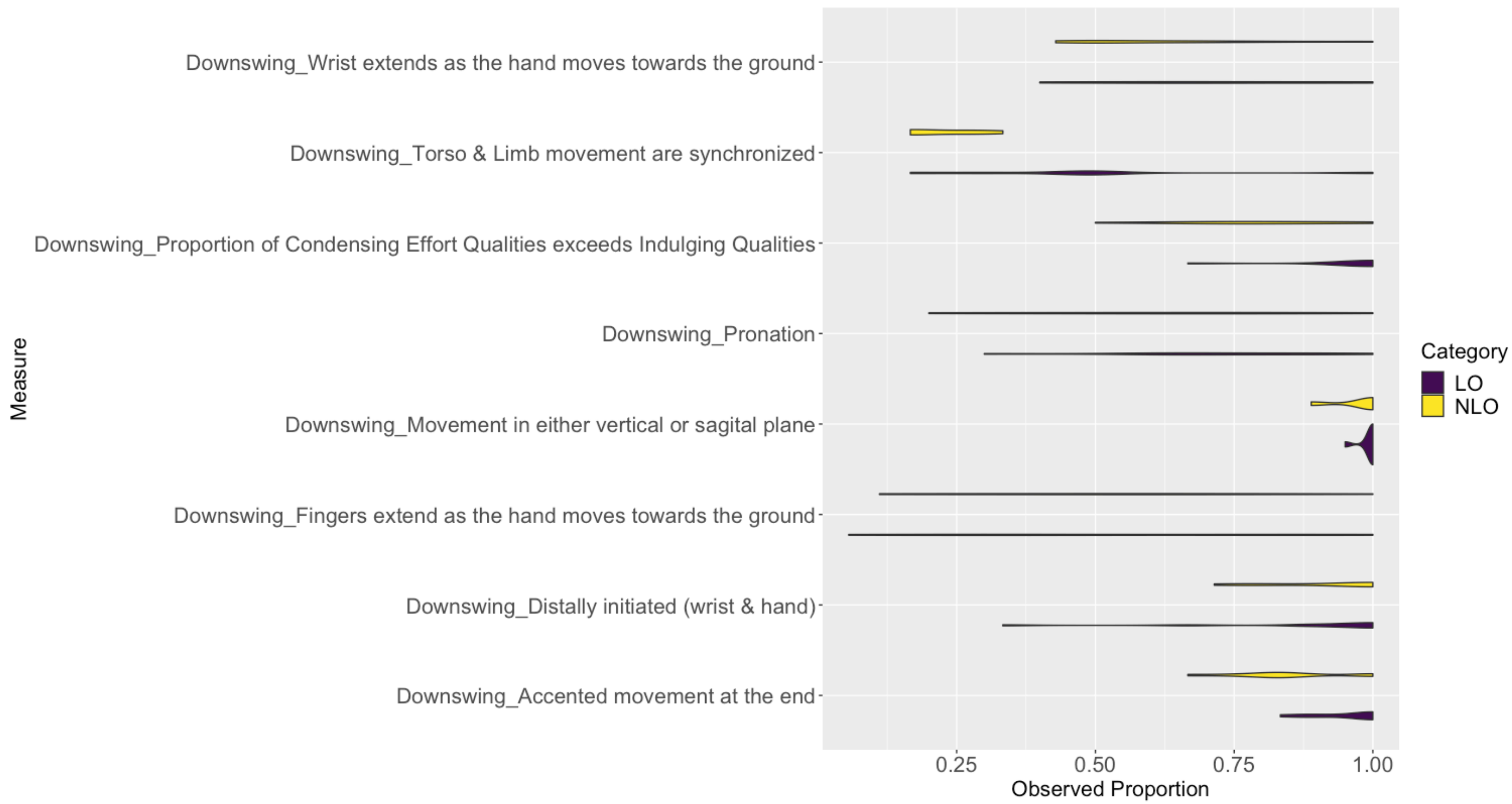

Figure 3.8. A violin plot featuring the different distributions of measures that occurred the "Downswing" phase of the pounding SH pattern are shown. The height of each point (i.e., violin shape) shows the range of the observed proportion of the occurrence, while the width of each point shows the frequency of the observed proportion of occurrence. In the "Proportion of Condensing Effort Qualities exceeds Indulging Effort Qualities" measure, the distributions for the LO and NLO categories are statistically significantly different. The subjects were more likely to perform this measure, in the "Downswing" phase, when they were looking at the stone.

CHAPTER FOUR

General Discussion

The occurrence of causally opaque and seemingly functionless behaviours – such as stone handling (SH) – is perplexing for researchers. However, solely because a researcher does not have access to the mechanisms causing the behaviour (i.e., causal opacity), this does not mean there are no underlying processes causing the behaviour (Kapitány & Nielsen, 2015; Legare & Souza, 2012). Additionally, although a behaviour may not have an ultimate function, or may not be an adaptation, it may very well have an effect (e.g., secondary adaptation, exaptation, malaptation, nonaptation) (for a review, see Linde-Medina, 2017). The main objective of this thesis was not to ask the question of *why*, but rather *how.* To do so, I asked the following questions: how do the kinematic (i.e., spatial-temporal, body and environmental relationships) and non-kinematic components (i.e., intensity, force, flow and rhythm) of two SH patterns, rubbing and pounding, compare (Chapter Two) (Foroud & Whishaw, 2006)? How does gaze direction correlate with the structure of either SH pattern during their execution (Chapter Three)? Finally, how does gaze direction affect the structure of rubbing and pounding comparatively, meaning, are there potential motoric themes that are consistent for each pattern (Chapter Three) (Pellis & Pellis, 1998)? This thesis aimed to answer these *how* questions, building a strong foundation for future work investigating the *why* (cf. Tinbergen, 1963).

Chapter One of this thesis outlined the implications and implementation of the "structure-to-function" framework used throughout this thesis (Martin & Caro, 1985; Moran, 1985). While this study was not able to shed light on the function of SH, the framework was still used to guide the analytical methods (i.e., movement analysis) and the questions asked in Chapter Two and Chapter Three.

In Chapter Two, I used Laban Movement Analysis (LMA) to examine the structure of two SH patterns, rubbing and pounding. More specifically, I described two different performances, a rougher/rigid performance and a gentler/fluid performance, of the two SH patterns. Additionally, I developed two rating scales (i.e., sequential lists of movements that together, illustrate the SH pattern – otherwise known as measures). These rating scales, the Rubbing Rating Scale (RRS) and Pounding Rating Scale (PRS), are not limited to this study and can be used in future analyses focused on the rubbing and pounding SH patterns.

In Chapter Three, I continued to build on the findings from Chapter Two and analysed the role of gaze direction on the execution of the rubbing and pounding SH patterns. I used Eshkol-Wachmann Movement Notation (EWMN) to validate the use of a subject's forehead direction as a proxy for gaze direction when their eyes were not visible. Once I validated using forehead direction as a proxy for gaze direction, I used the RRS and PRS to score multiple samples of the rubbing and pounding SH patterns when the subject was looking towards the stone and when looking away from the stone. The results from this chapter indicate that when the subject was looking at the stone when performing either the rubbing SH pattern or the pounding SH pattern, its movements were more constrained with a higher presence of Condensing Effort Qualities (these qualities typically appear in a movement as power, constraint, and tension) (Foroud & Whishaw, 2006). Additionally, when the subjects were not looking at the stone, in the pounding SH pattern, their torso and limb movement were not synchronized indicating a possible disconnect between where they were attending to and their engagement in the SH bout. Taken together, these results begin to reveal a possible attentional mechanism(s) involved in the execution of SH.

As Tinbergen (1963) stated, to gain a comprehensive understanding of an observable behaviour, we must start by providing a detailed description of the behaviour and its structure. The use of structural analytical systems, such as those used in this thesis (i.e., EWMN and LMA) allows for an in-depth view of a behavioural sequence while also showing how all the parts of a movement interact with one another as music notes do when they combine to form a song (Fentress, 2008; Foroud & Pellis, 2021; Golani, 1992**)**. While movement analysis has been less common in the field of psychology, there has been a resurgence that only speaks to the power of using these methods (see Rosenbaum, 2005). Rosenbaum (2005) provides multiple reasons for a lack of movement analysis in the field of psychology, including the philosophical origin of the field and the divide between the fields of neuroscience and psychology. The recent boom in multi-disciplinary research projects has led to the increase in motor analysis across fields.

Even if a behavioural expression appears different, compared to what the researcher has known to be a "typical" presentation of that behaviour, when performed by different individuals or in different contexts, a structural analysis has the potential to reveal a consistent motoric theme (Pellis & Pellis, 1998). The correlation of a motoric theme and an underlying cognitive mechanism, such as the correlation between gaze direction towards a stone and higher frequencies of Condensing Effort Qualities, may aid in de-mystifying the cause and potential effect(s) or function(s) of the behaviour. The main objective of this MSc thesis was to continue the exploration of the structure of SH, a repetitive, arbitrary, and seemingly purposeless behaviour, in relation to gaze direction. In Chapter Three, I referenced the theoretical background of the behavioural category – fidgeting. I used the hypothesized relationship between attention and fidgeting to propose that in certain contexts, SH may be a form of fidgeting due to a potential attentional state that may be associated with SH when the subjects gaze is no longer on the stone – mind wandering. The following sections will elaborate on this potential relationship.

SH is an ideal model behaviour to investigate the relationship between object play, fidgeting, attentional states, and stress as was partly done in this thesis in Chapter Three. Rather than state that SH is either a form of fidgeting or a form of object-play, based on the results of this study, I propose that these categories are not mutually exclusive. In other words, SH as a behavioural category may consist of multiple behavioural expressions reflecting playful motivations as well as varying attentional states. The limited results presented in this thesis indicate that when the subjects were not visually attending to the stone, and possibly not attending to their own engagement in the SH activity, the structure of the movements differed. When the subjects were looking towards the stone, the movements were more powerful as was indicated by the presence of Condensing Effort Qualities. It is possible that the subjects are in a playful state, even a possible state of flow when they were looking at the stone (Csikszentmihalyi, 1990). When the subjects appeared to be distracted and were no longer looking at the stones, there were less Condensing Effort Qualities in the execution of the SH pattern, therefore suggesting that the subject was less engaged in the behaviour and possibly in a state of mind wandering. While the results presented in this thesis are preliminary, they serve as the foundation for future studies comparing object play and fidgeting in both non-human and human animals.

Object Play and Fidgeting

In Chapter One, I indicated that SH has primarily been examined within the category of object play. The criteria for play in non-human animals are as follows: play is [1] incompletely functional compared to its fully functional counterpart (i.e., the rolling of a potato up and down one's feet versus rotating the potato to find the best location to bite), [2] voluntary and intrinsically rewarding, [3] modified structurally from its functional counterpart (i.e., exaggerated, incomplete, or more various), [4] repetitive, but not stereotypic or rigid in its repetitions, and [5] performed in a low stress individual who is free from environmental demands (i.e., hunger, poor weather, agonistic interactions, etc.) (Burghardt, 2005). SH is a form of object play (Nahallage et al., 2016; Pellis et al., 2019). SH is variable in both its structure and the contexts in which it occurs (Pelletier, 2017; Pelletier et al., 2017).

One of the main criteria of play for both humans and non-human animals is that play occurs when an individual is free of individual and environmental stressors (Burghardt, 2005; Gray, 2009; Vygotsky, 1967, but see Pellis & Burghardt, 2017 for evidence that play can be stimulated during states of mild to moderate stress). Pellegrini (2013) has suggested that we do not know exactly what it means to be in an alert and non-stressed state; but Gray (2013) has proposed that the aforementioned state (i.e., alert and non-stressed) is what has been called flow (Csikszentmihalyi, 1990). Flow is the cognitive state of attention in which an individual focuses solely on the task at hand, time flies, and the individual is no longer distracted by their own stressors or environmental variables (Csikszentmihalyi, 1990). One cannot reach a state of flow if one is distracted by stressors or anxieties. Flow is guided by an internal evaluation of the situation (criterion #1: the assessment of the challenge at hand and self-directed guidance through the challenge), enjoyment (criterion #2: intrinsic motivation), and expectations of what is to come (criterion #3: the guiding through an individual's own set of rules). Therefore, a state of flow is likely to occur during bouts of play in both human and non-human animals.

Seemingly opposite to the state of flow, is the state of mind wandering (daydreaming). Smallwood & Schooler (2006) summarized mind wandering as a shift of focus away from a task and towards internal thoughts. There are two distinct categories of mind wandering that are likely due to different cognitive mechanisms, and thus may result in different behavioural expressions (Seli et al., 2016). On the one hand, deliberate mind wandering occurs when an individual chooses to shift their thoughts inward (Seli et al., 2016). On the other hand, spontaneous mind wandering occurs when an individual is unaware of the shift into a mind wandering state; it is a non-deliberate sequence of events. It has been hypothesized that spontaneous mind wandering is induced more frequently by negative emotional states, such as stress (Crosswell et al., 2020; Poerio et al., 2013). Similarly, Smallwood et al. (2009) found that being in a negative emotional state did increase bouts of spontaneous mind wandering and the time it took for an individual to return to, and successfully complete, a task. However, other research has suggested that a negative mood may be caused by spontaneous mind wandering, rather than inducing spontaneous mind wandering (Killingsworth & Gilbert, 2010). Thus, the directional relationship between a negative mood and mind wandering remains unclear.

One behavioural proxy that has been used to identify bouts of mind wandering is fidgeting (Carriere et al., 2013; Seli et al., 2014).

The presumed roles of fidgeting have gone beyond an indicator for mind wandering while providing support as to why fidgeting and mind wandering are likely to co-occur (Carriere et al., 2013; Seli et al., 2014). As stated by Reinecke and co-authors (2020), fidgeting may be a motor phenomenon associated with multiple states and mental disorders. The ubiquitous quality of fidgeting has also led to the behaviour being defined differently at the researchers' discretion making cross-study comparisons difficult. Fidgeting has been hypothesized as a form of body regulation in the way of weight loss, a way to improve blood circulation and overall physical fitness, emotional regulation, and attentional regulation (Andrade, 2010; Belak et al., 2017; Farley et al., 2013; Graziano et al., 2018; Hagger-Johnson et al., 2016; Mehrabian & Friedman, 1986; Morishima et al., 2016; Morris & Warne, 2017; Perrykkad & Hohwy, 2020; Reinecke et al. 2020; for a review on the relationship between sustained attention and stress, see Hancock, 1989).

While much remains unknown regarding fidgeting, it is possible to say that fidgeting is closely tied to levels of stress and varying states of attention, a potential point of differentiation from object-play (cf. Burghardt, 2005; Perrykhad & Hohwy, 2020). In non-human animals, fidgeting closely resembles the behavioural category of displacement behaviours (e.g., scratching). Displacement behaviours have been described as behaviour performed by an individual instead of the functional behaviour that would be expected to be seen in that specific context (Maestripieri et al., 1992; Mohiyeddini & Semple, 2013; Tinbergen, 1952; Troisi, 2002). Displacement behaviours have been successfully used as behavioural proxies for stress in both humans and non-human primates (Maestripieri et al., 1992; Troisi, 2002). Therefore, if fidgeting, or potentially displacement behaviours, are a behavioural indicator of stress as well as states of attention such as mind wandering, then object manipulation during bouts of mind wandering or stress may not be object play but rather fidgeting. However, forms of play, especially social play, have been noted to help an individual cope with stress and prepare them for future stressful or potentially dangerous situations (Fagen & Fagen, 2004; Norscia & Palagi, 2010; for further review of the role of play on stress, see Pellis & Pellis, 2021). While these findings seem contradictory to the argument presented here, they are actually complementary and provide a bridge between what we know of object play in non-human animals and fidgeting which has not been directly described in non-human animals, with the exception of one study conducted by Young et al. (2012) describing a behavioural indicator of stress as "fidgeting" in horses. However, this one example does not address object-directed fidgeting.

Limitations of Present Study and Future Directions

A primary limitation of this study was the low intra-scorer reliability score for the pounding SH pattern. The objective definitions of each measure in the rating scale for the pounding SH pattern did not include the magnitude of a movement for it to have counted as "occurring." This discrepancy may have resulted in the low intra-scorer reliability score. Additionally, as I continued to score the SH sequences, I improved my ability to score and may have been more confident when scoring the behaviour the second time. Some of the variation in the results presented in Chapter Two and Chapter Three is random noise attributable to variation in scoring practices. Therefore, my estimated associations are likely to be weaker than they would have been if I had achieved a higher intra-rater reliability. I will continue to practice using LMA to improve my skills. Additionally, an inter-scorer reliability test will be conducted with an expert certified in LMA.

Despite the novelty of the findings presented in Chapter Three, it is important to emphasize that visual attention and awareness are not synonymous (Lamme, 2003). While visual attention and awareness are intertwined, it is possible to look at an object but not be conscious of the object. For example, when driving down the road, it is likely that you will see cars of many colors, but if you do not apply or incorporate the information into your thoughts, you may not be truly aware of the color of the car (O'Regan & Noë, 2001). As stated by O'Regan and Noë (2001):

> "For a creature (or a machine for that matter) to possess visual awareness what is required is that, in addition to exercising the mastery of the relevant sensorimotor contingencies, it must make use of this exercise for the purposes of thought and planning" (p. 944).

In other words, for visual attention to become visual awareness, there needs to be some integration of the visual components (e.g., the stone is flat) into the thoughts of the viewer (e.g., this stone is a good choice for rubbing because it is flat) (O'Regan & Noë, 2001). Without further tests, it is not possible to know at what "level" the monkeys were "seeing" the stones.

Furthermore, while all the behavioural sequences in Chapter Three were selected because they occurred in a seemingly neutral state rather than an obviously known aroused or agonistic state, it was not feasible to select samples in which the individual was surrounded by the same noise level, conspecifics, tourists, and staff members. The population at the Ubud Monkey Sanctuary are exposed to high levels of human interference and interactions, thus may experience potential effects of urbanization (e.g., increasing proximity to a socially bonded partner during close encounters with tourists) (cf. Maréchal et al., 2016). Additionally, the size of the stones used by the subjects were not uniform. Cenni et al. (in press) recently found that the size of the stone significantly influenced the duration of the manipulation and the versatility of SH patterns performed. More specifically, subjects pound the stones for a longer duration when the stones are considered small (less than three centimeters in length) to medium (between three and five centimeters in length) in size rather than large (greater than five centimeters in length). Alternatively, subjects rub the stones longer when the stones are considered medium to large in size, rather than small. Overall, SH versatility (i.e., number of SH patterns performed across subjects) is higher for small to medium sized stones, rather than large stones. Similarly, Pelletier et al. (2017) found that different SH patterns require different grips on the stone. Since these variables (i.e., the size of the stone and the duration of engagement in SH) were not controlled for in this study, the results described may reflect differing stone properties.

I did not examine the movement composition of the rubbing and pounding SH pattern performed by subjects in states of stress, and so it is not yet possible to make any substantial claims about the variations of the two SH patterns being correlated to stress or being expressions of object play or fidgeting beyond the potential view previously proposed. Additionally, I did not study the frequency of the SH bouts or the SH patterns based on different conditions (e.g., stress), or the frequency of bi- versus uni-manual manipulations (Leca et al., 2010a).

While multiple studies on fidgeting have been conducted with humans in clinical or laboratory settings, there are fewer studies that have focused on fidgeting in a more “naturalistic” environment for humans, such as a classroom or dentist’s office, using observational techniques (Barash, 1974; da Câmara et al., 2018; Farley et al., 2013; Graziano et al., 2018; Reinecke et al., 2020). Furthermore, only a few studies have investigated the movement or structural composition of fidgeting performed by humans in these naturalistic environments (Farley et al., 2013; Reinecke et al., 2020). Future studies will aim to evaluate the movement composition of object-directed fidgeting and object play with the same or similar item performed by children in a classroom environment, thereby providing a basis for comparison for the SH behaviour demonstrated by the Balinese long-tailed macaques. Until we are able to apply a fine-grained analysis of the movement structure (including the combination of these movements into a longer sequence) of fidgeting in humans, as has been done with object exploration and object play (Hughes, 1978; Hutt, 1966), we will be unable to directly compare fidgeting behaviour in humans to the fidgeting-like behaviour performed by non-human primates. A future cross-species comparative study will further inform us of the potentially similar underlying cognitive processes (e.g., waning attention) involved with non-instrumental object manipulation.

Conclusion

In summary, this thesis looked at a form of non-instrumental, playful, and repetitive object-directed manipulation performed by Balinese long-tailed macaques (*Macaca fascicularis*) – SH. To investigate the potential attentional mechanisms associated with SH, I used the current literature surrounding another non-instrumental, and repetitive manipulation performed by humans – fidgeting – to guide the exploration of two SH patterns (i.e., rubbing and pounding) using two universal movement analysis systems (EWMN and LMA). The two main findings of this thesis are [1] the orientation of the subject while they are engaged in SH differs across acts, leading to at least two variations within each SH pattern (i.e., rubbing and pounding), and [2] the gaze direction of the subject influences the kinematic and non-kinematic structure of the two SH patterns (i.e., rubbing and pounding), with the subject performing the SH pattern in a more constrained manner while looking at the stone. These results contribute to our understanding of how attentional processes interact with the performance of SH across two different SH patterns. This thesis is the first to draw parallels between fidgeting and a form of non-instrumental object manipulation performed by non-human primates.

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Appendix A

Commonly used symbols in Laban Movement Analysis

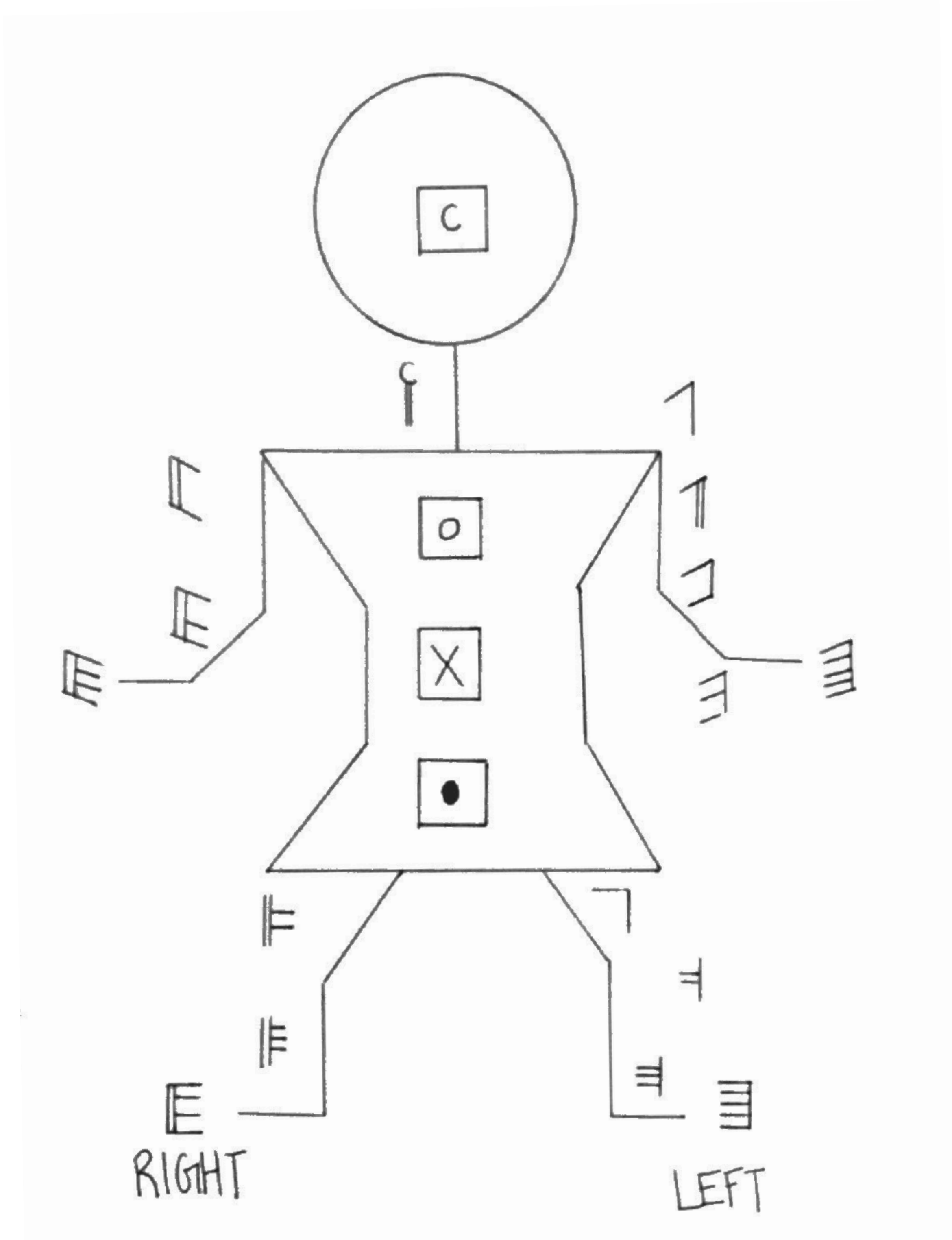
General Notation Staff	
	Double bar lines *Indicate the beginning and end of a movement sequence*
	Single bar lines *Can be used to describe timing*
	Generic action stroke

Pauses	
	Pause in the movement
	'Active Stillness' *Subject is still, but the position is not static, qualitative expression is active even in the absence of movement*

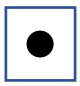
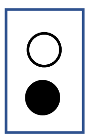
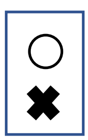
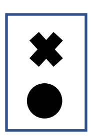
Relationships	
	Near

	Contact
	Grasp
	Release

Main Body Symbols

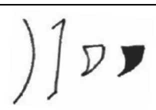


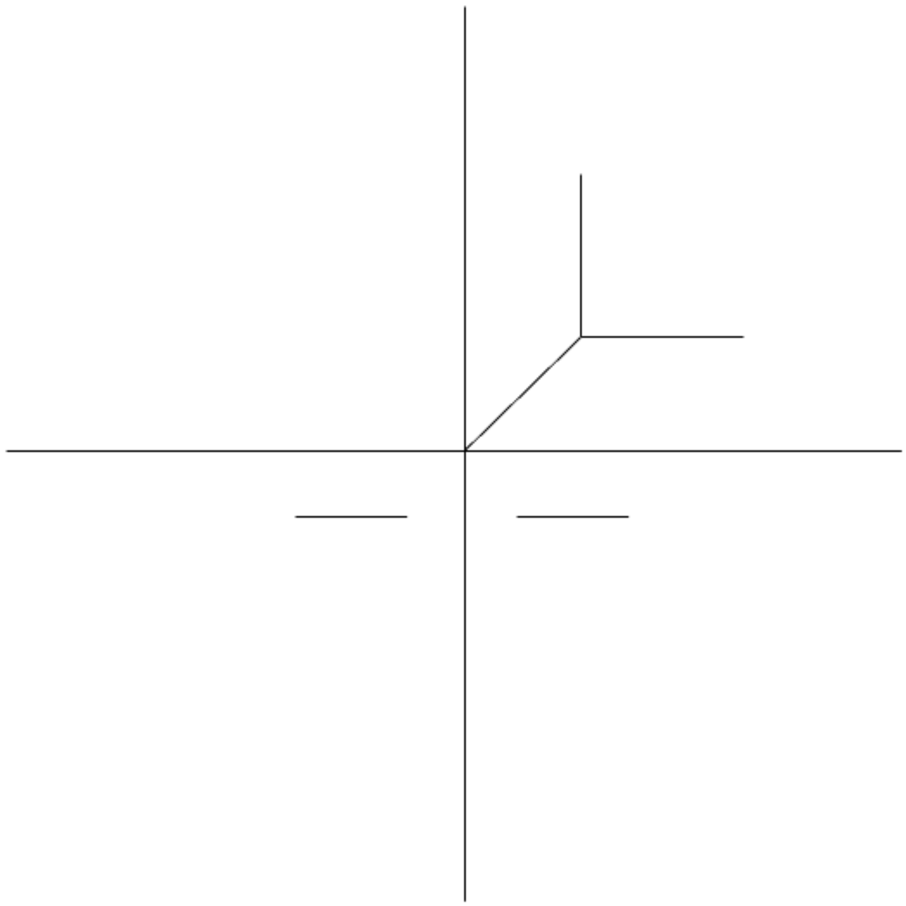
Main Body Symbols

Body Symbols	
	Generic symbol for the whole body
	Waist
	Pelvis
	Torso
	Upper torso
	Lower torso

Body Actions	
	Extension Major extension Ad lib size of extension

	Flexion Major flexion Ad lib size of flexion
	Rotate counterclockwise Rotate clockwise

Effort	
	Generic Effort Action Stroke
	Various bows and accent marks for describing Effort Rhythms

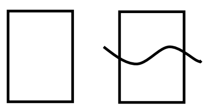
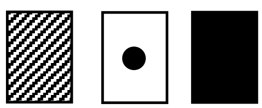


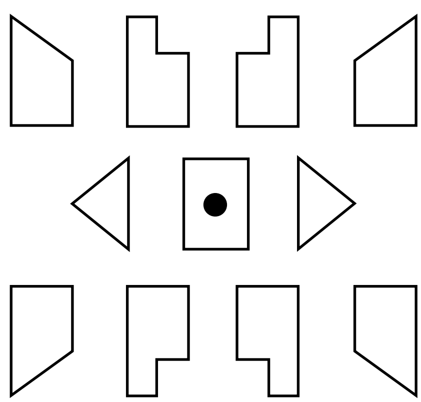
Effort Graph

Effort Symbols

Effort Factors		Single Effort Elements			
		Indulging Efforts		Condensing Efforts	
	Weight Effort		Light Weight		Strong Weight
	Time Effort		Sustained Time		Quick Time
	Space Effort		Indirect Space		Direct Space
	Flow Effort		Free Flow		Bound Flow

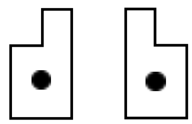
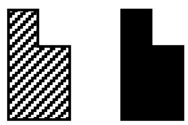
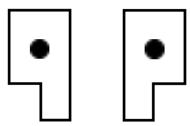
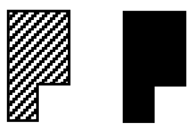
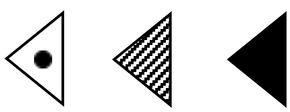
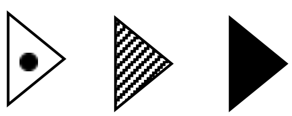
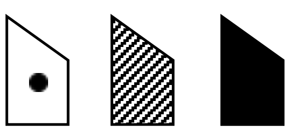
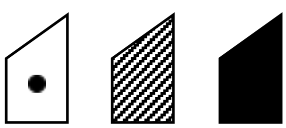
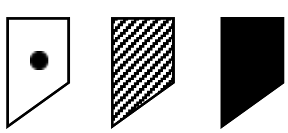
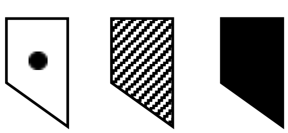
Space Symbols

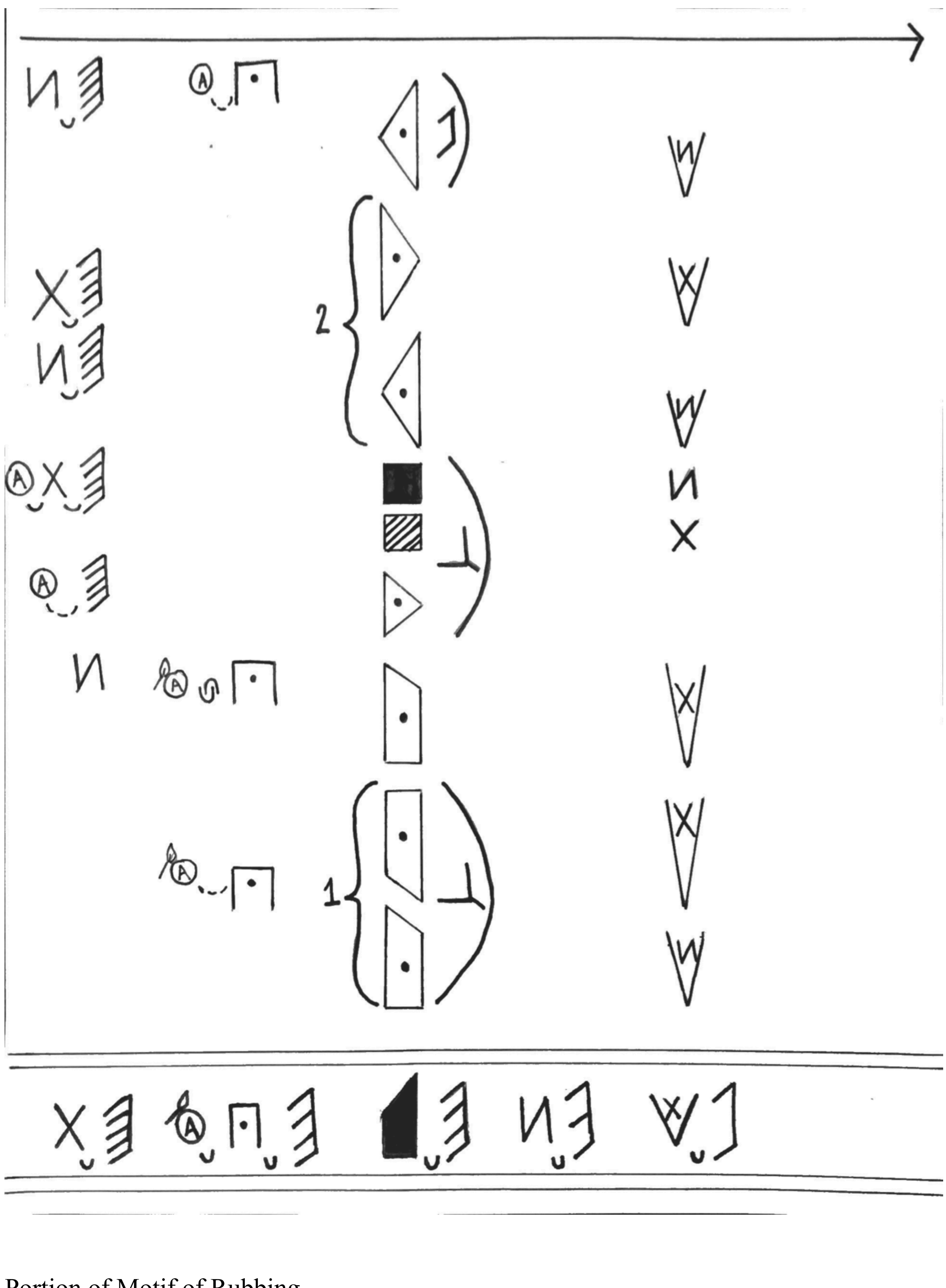
Space	
	Moving towards Moving away
	Generic spatial direction Ad lib spatial direction
	High Middle Low



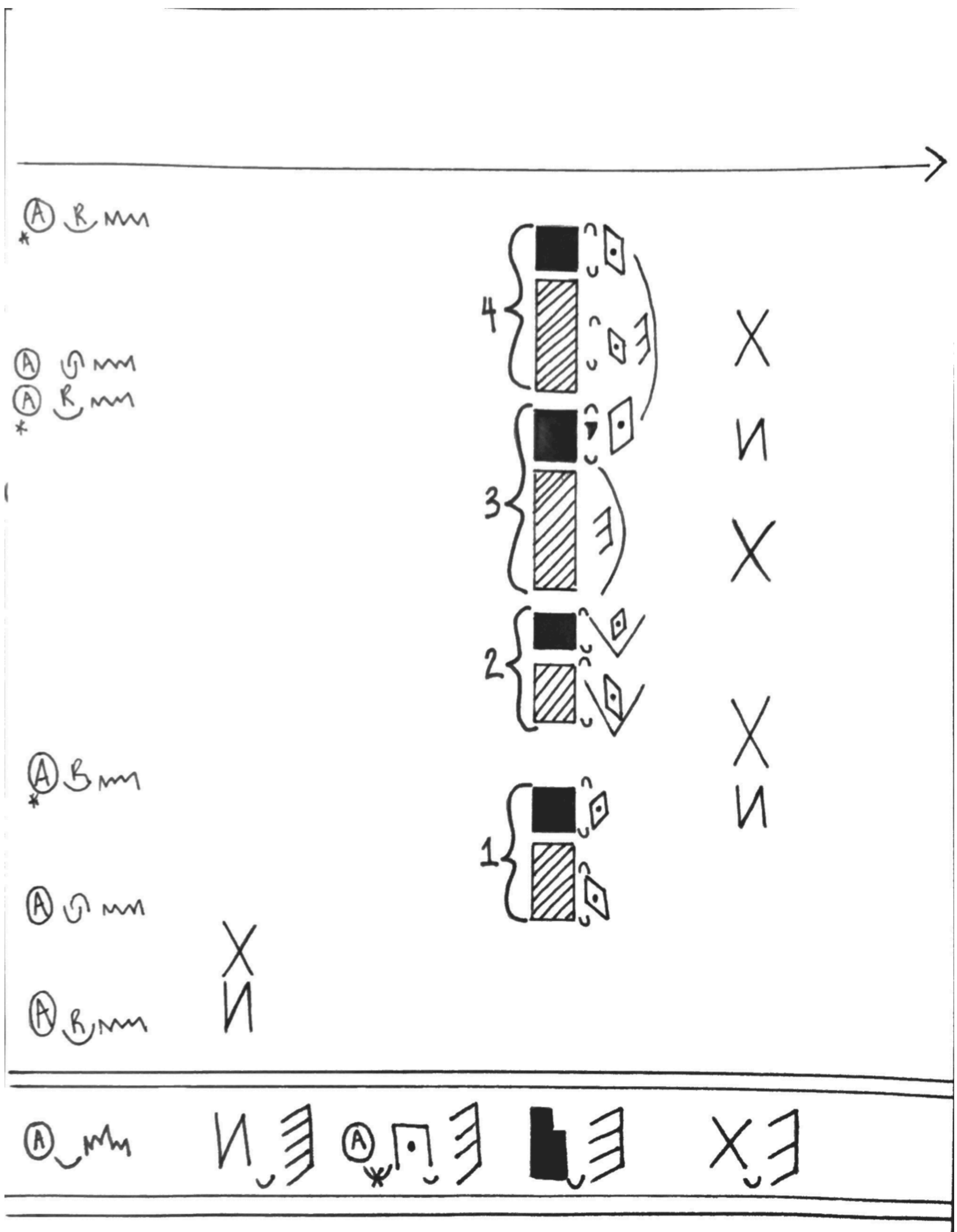
Spatial Directions Graph

Symbols for Spatial Directions

Spatial Directions	
	Forward
	Simultaneously Forward and High Simultaneously Forward and Low
	Backward
	Simultaneously Backward and High Simultaneously Backward and Low
	Sideward Left Simultaneously Sideward Left & High Simultaneously Sideward Left & Low
	Sideward Right Simultaneously Sideward Right & High Simultaneously Sideward Right & Low
	Simultaneously Sideward Left & Forward Simultaneously Sideward Left, Forward, & High Simultaneously Sideward Left, Forward, & Low
	Simultaneously Sideward Right & Forward Simultaneously Sideward Right, Forward, & High Simultaneously Sideward Right, Forward, & Low
	Simultaneously Sideward Left & Backward Simultaneously Sideward Left, Backward, & High Simultaneously Sideward Left, Backward, & Low
	Simultaneously Sideward Right & Backward Simultaneously Sideward Right, Backward, & High Simultaneously Sideward Right, Backward, & Low



Portion of Motif of Rubbing



Portion of Motif of Pounding

Appendix B

Rubbing Rating Scale consisting of the six phases, individual measures, and objective definitions of each measure.

Phase	Measure	Definition
Starting Orientation		This phase encompasses the starting position of the subject at the beginning of a rubbing act (this phase, and corresponding measures, can occur at the start of a SH bout or within a SH sequence, meaning the subject may already have been engaged in SH).
Starting Orientation	Face orientated towards stone	The subject's forehead and face is pointed at the stone they are manipulating.
Starting Orientation	Body orientated towards stone	The midline of the subject's torso is pointed at the stone they are manipulating.
Outward (Away from the body)		This phase encompasses the main movements that compose the outward motion of the forelimb(s), in which the subject manipulates the stone away from their body, creating more distance between their torso and the stone.
Outward (Away from the body)	Torso and limb movement are synchronized	The subject's torso and the limb manipulating the stone move together at the same time; the torso supports the limb, moving in coordination with the limb, as the stone is moved outward away from the subject's body.
Outward (Away from the body)	Distally initiated (wrist and hand)	The outward limb movement begins with a movement from either the subject's wrist or their hand. The wrist or hand moves first rather than the elbow, shoulder, or torso.
Outward (Away from the body)	Wrist flexes as hand moves away from torso	As the subject moves their hand away from their body, the wrist bends so that the distance between the palm of the hand and the underside of the forearm shortens.
Outward (Away from the body)	Fingers extend as hand moves away from torso	As the subject moves their hand away from their body, the fingers lengthen out, decreasing the bend at the knuckles.

Outward (Away from the body)	Hand moves in a straight pathway	As the subject moves their hand away from their midline, the hand moves straight, with no curves or meandering.
Outward (Away from the body)	Proportion of Condensing Effort Qualities exceeds Indulging Effort Qualities	Throughout the entire outward phase of movement, there are more Condensing Effort Qualities (Strong Weight, Bound Flow, Quick Time, and Direct Space) than Indulging Effort Qualities (Light Weight, Free Flow, Sustained Time, and Indirect Space). This measure did not focus on the specific Effort Qualities and instead focused on the gradient they stem from, Condensing to Indulging. Effort Qualities cannot be perceived by viewing a video frame-by-frame. To quantify the Effort Qualities, the video has to be viewed at its normal speed.
First Adjustment		Following the outward phase, this phase encompasses the main movements that occur when the stone was no longer moving farther away from the body but was not yet moving back towards the body. During this phase, movements appeared to be small positioning changes on the stone, while the stone remained in one location.
First Adjustment	Wrist and/or fingers extend	Either the subject's wrist or fingers extend; for the wrist this looks like the distance between the back of the hand and the backside of the forearm shortens; for the fingers, this looks like the fingers are lengthening out, decreasing the bend at the knuckles.
First Adjustment	Supination	The subject's forearm, wrist and hand (i.e., lower arm) rotates so that the palm faces upwards or forwards.
First Adjustment	Release of contact with stone as hand lifts	The subject may make small movements in the adjustment phase, one of them being releasing the stone prior to grabbing the stone again. If their hand is no longer touching the stone after loosening their grasp, they have then released contact with the stone.

First Adjustment	Pronation	The subject's forearm, wrist and hand (i.e., lower arm), rotates so that the palm faces downwards or backwards.
First Adjustment	Re-contact with stone as hand lowers	If the subject did not engage in measure 3.3, then they cannot score a 1 for this measure. If they did engage in measure 3.3, and they return their hand to the stone, they have regained contact with the stone.
First Adjustment	Wrist and/or fingers flex	Either the subject's wrist or fingers flex; for the wrist this looks like the distance between the palm of the hand and the underside of the forearm shortens; for the fingers, this looks like the fingers bend, increasing the bend at the knuckles.
First Adjustment	Lateral deviation at the wrist	The subject's wrist bends either to the left or the right; the hand does not move in the vertical plane meaning the palm of the hand neither gets closer to the underside of the forearm nor farther from it.
Inwards (Towards the body)		This phase encompasses the main movements that compose the outward motion, in which the subject manipulates the stone away from their body, creating more distance between their torso and the stone.
Inwards (Towards the body)	Torso & limb movement are synchronized	The subject's torso and limb manipulating the stone move together at the same time; the torso supports the limb, moving in coordination with the limb, as the stone is moved inward, towards the subject's body.
Inwards (Towards the body)	Distally initiated (wrist and hand)	The inward movement begins with a movement from either the subject's wrist or their hand. The wrist or hand moves first rather than the elbow, shoulder or torso.
Inwards (Towards the body)	Wrist extends as hand moves towards torso	As the subject moves their hand towards their body, the wrist bends so that the distance between the back of the hand and the backside of the forearm shortens.

Inwards (Towards the body)	Fingers flex as hand moves towards torso	As the subject moves their hand towards their body, the fingers bend, increasing the bend at the knuckles.
Inwards (Towards the body)	Hand moves along straight pathway	As the subject moves their hand towards their body, the hand moves straight, with no curves or meandering.
Inwards (Towards the body)	Proportion of Condensing Effort Qualities exceeds Indulging Effort Qualities	Throughout the entire inward phase of movement, there are more Condensing Effort Qualities (Strong Weight, Bound Flow, Quick Time, and Direct Space) than Indulging Effort Qualities (Light Weight, Free Flow, Sustained Time, and Indirect Space). This measure did not focus on the specific Effort Qualities and instead focused on the gradient they stem from, Condensing to Indulging. Effort Qualities cannot be perceived by viewing a video frame-by-frame. To quantify the Effort Qualities, the video has to be viewed at its normal speed.
Second Adjustment		Following the inward phase, this phase encompasses the main movements that occur once the stone has been brought inwards, towards the subject's body but before the subject either ceases to handle the stone or initiates another rub. During this phase, movements appeared to be small positioning changes on the stone, while the stone remained in one location. In this phase, for the measures to receive a score of 1, they must happen in the listed order. For example, if measure 5.2 occurred after measure 5.4, it would still receive a score of 0. The exception is measure 5.6, which could receive a 1 independent of the order of occurrence.
Second Adjustment	Wrist and/or fingers extend	Either the subject's wrist or fingers extend; for the wrist this looks like the distance between the back of the hand and the backside of the forearm shortens; for the fingers, this looks like the fingers are lengthening out, decreasing the bend at the knuckles.

Second Adjustment	Supination	The subject's forearm, wrist and hand (i.e., lower arm), rotates so that the palm faces upwards or forwards.
Second Adjustment	Release of contact with stone as hand lifts	The subject may make small movements in the adjustment phase, one of them being releasing the stone prior to grabbing the stone again. If their hand is no longer touching the stone after loosening their grasp, they have then released contact with the stone.
Second Adjustment	Pronation	The subject's forearm, wrist and hand (i.e., lower arm), rotates so that the palm faces downwards or backwards.
Second Adjustment	Re-contact with stone as hand lowers	If the subject did not engage in measure 5.3, then they cannot score a 1 for this measure. If they did engage in measure 5.3 and they return their hand to the stone, they have regained contact with the stone.
Second Adjustment	Lateral deviation at the wrist	The subject's wrist bends either to the left or the right, the hand does not move in the vertical plane meaning the palm of the hand neither gets closer to the underside of the forearm nor farther from it.
Ending Orientation		This phase encompasses the ending position of the subject at the end of a rubbing act regardless if the subject continued to engage in stone handling, or if they ceased to stone handle.
Ending Orientation	Face orientated towards stone	The subject's forehead and face is pointed at the stone they are manipulating. This measure was derived based on previous analyses using EWMN to determine that the forehead is a suitable proxy for gaze direction when the subject's eyes were not visible.
Ending Orientation	Body orientated towards stone	The midline of the subject's torso is pointed at the stone they are manipulating.

Pounding Rating Scale consisting of the six phases, individual measures, and objective definitions of each measure.

Phase	Measure	Definition
Starting Orientation		This phase encompasses the starting position of the subject at the beginning of a pounding act.
Starting Orientation	Face orientated towards stone	The subject's forehead and face are pointed at the stone they are manipulating.
Starting Orientation	Body orientated towards stone	The midline of the subject's torso is pointed at the stone they are manipulating.
Upswing		This phase encompasses the main movements that compose the upward motion, in which the subject manipulates the stone off and away from the ground.
Upswing	Torso & limb movement are synchronized	The subject's torso and limb manipulating the stone move together at the same time; the torso supports the limb, moving in coordination with the limb, as the stone is lifted off of the ground.
Upswing	Distally initiated (wrist and hand)	The upward movement begins with a movement from either the subject's wrist or their hand. The wrist or hand moves first rather than the elbow, shoulder, or torso.
Upswing	Wrist flexes as hand moves away from the ground	As the subject lifts the stone off of the ground, the wrist bends so that the distance between the palm of the hand and the underside of the forearm shortens.
Upswing	Fingers flex as hand moves away from the ground	As the subject lifts the stone off of the ground, the fingers bend, increasing the bend at the knuckles.
Upswing	Supination	The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces upwards or forwards.
Upswing	Movement in either vertical or sagittal plane	As the subject raises their arm with the stone away the ground, the movement remains in the vertical or sagittal plane.

Upswing	Proportion of Condensing Effort Qualities exceeds Indulging Qualities:	Throughout the entire upward phase of movement, there are more Condensing Effort Qualities (Strong Weight, Bound Flow, Quick Time, and Direct Space) than Indulging Effort Qualities (Light Weight, Free Flow, Sustained Time, and Indirect Space). This measure did not focus on the specific Effort Qualities and instead focused on the gradient they stem from, Condensing to Indulging. To quantify the Effort Qualities, the video has to be viewed at its normal speed.
Adjustment		Following the upward phase, this phase encompasses the main movements that occur at the highest point of the upward phase when the stone was no longer moving in the vertical or sagittal plane. During this phase, movements appeared to be small positioning changes on the stone, prior to the downswing phase.
Adjustment	Forelimb rotation	The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces upwards or forwards (i.e., supination) or so that the palm faces downwards or backwards (i.e., pronation).
Adjustment	Wrist extends and/or flexes	The subject's wrist bends so that the distance between the back of the hand and the backside of the forearm shortens (i.e., extension) or so that the distance between the palm of the hand and the underside of the forearm shortens (i.e., flexion).
Adjustment	Fingers extend and/or flex	The subject's fingers bend so that the fingers are lengthening out, decreasing the bend at the knuckles (i.e., extension) or so that the fingers bend, increasing the bend at the knuckles (i.e., flexion).
Adjustment	Lateral deviation at the wrist	The subject's wrist bends either to the left or the right, the hand does not move in the vertical plane meaning the palm of the hand neither gets closer to the underside of the forearm nor farther from it.
Downswing		This phase encompasses the main movements that compose the downward motion, in which

		the subject manipulates the stone closer to the ground, eventually completely returning the stone to the ground.
Downswing	Torso & limb movement are synchronized	The subject's torso and limb manipulating the stone move together at the same time; the torso supports the limb, moving in coordination with the limb, as the stone is returned to the ground.
Downswing	Distally initiated (wrist and hand)	The downward movement begins with a movement from either the subject's wrist or their hand. The wrist or hand moves first rather than the elbow, shoulder or torso.
Downswing	Wrist extends as the hand moves towards the ground	As the subject moves the stone towards the ground, the wrist bends so that the distance between the back of the hand and the backside of the forearm shortens.
Downswing	Fingers extend as the hand moves towards the ground	As the subject moves the stone towards the ground, the fingers lengthen out, decreasing the bend at the knuckles.
Downswing	Pronation	The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces downwards or backwards.
Downswing	Movement in either vertical or sagittal plane	As the subject lowers their arm with the stone towards the ground, the movement remains in the vertical or sagittal plane.
Downswing	Proportion of Condensing Effort Qualities exceeds Indulging Qualities	Throughout the entire downward phase of movement, there are more Condensing Effort Qualities (Strong Weight, Bound Flow, Quick Time, and Direct Space) than Indulging Effort Qualities (Light Weight, Free Flow, Sustained Time, and Indirect Space). This measure did not focus on the specific Effort Qualities and instead focused on the gradient they stem from, Condensing to Indulging. To quantify the Effort Qualities, the video has to be viewed at its normal speed.
Transition		Following the downswing phase, this phase encompasses the main movements that occur once the stone is touching the ground, but before

		the subject either ceases to perform SH or initiates another pound. During this phase, movements appeared to be small positioning changes on the stone, while the stone remained in one location. During this phase, for the measures to receive a score of 1, they must happen in the listed order. For example, if measure 5.2 occurred after 5.4, it would still receive a score of a 0. The exception is measure 5.7 which could receive a 1 independent of the order of occurrence.
Transition	Wrist and/or fingers extend	Either the subject's wrist or fingers extend; for the wrist, this looks like the distance between back of the hand and the backside off the forearm shortens; for the fingers, this looks like the fingers are lengthening out, decreasing the bend at the knuckles.
Transition	Supination	The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces upwards or forwards.
Transition	Release of contact with stone as hand lifts	The subject may make small movements in the adjustment phase, one of them being releasing the stone prior to grabbing the stone again. If their hand is no longer touching the stone after loosening their grasp, they have then released contact with the stone.
Transition	Pronation	The subject's forearm, wrist and hand (i.e., lower arm) rotate so that the palm faces downwards or backwards.
Transition	Re-contact with stone as hand lowers	If the subject did not engage in measure 5.3, then they cannot score a 1 for this measure. If they did engage in measure 5.3 and they return their hand to the stone, they have regained contact with the stone.
Transition	Wrist and/or fingers flex	Either the subject's wrist or fingers flex; for the wrist, this looks like the distance between the palm of the hand and the underside of the forearm shortens; for the fingers, this looks like the fingers bend, increasing the bend at the knuckles.

Transition	Lateral deviation at the wrist	The subject's wrist bends either to the left or the right; the hand does not move in the vertical plane meaning the palm of the hand neither gets closer to the underside of the forearm nor farther from it.
Ending Orientation		This phase encompasses the ending position of the subject at the ending of a pounding act regardless of whether the subject continued to engage in SH, or if they ceased to perform SH.
Ending Orientation	Face orientated towards stone	The subject's forehead and face are pointed at the stone they are manipulating.
Ending Orientation	Body orientated towards stone	The midline of the subject's torso is pointed at the stone they are manipulating.

Appendix C

Table showing each study subjects' identity in this thesis, their age group, sex, the SH pattern(s) they performed, or the specific analysis they were included in. The age class is based on the classification used in the specific study.

ID	Age	Sex	Stone Handling Pattern Performed or Specific Analysis
White Eyebrows	Adult	Male	Pounding
Zsolt	Adult	Male	Pounding / Rubbing
Zeus	Adult	Male	Pounding
Anvil	Adult	Male	Pounding
Danger	Adult	Male	Pounding / Rubbing
Little Finger	Adult	Male	Pounding / Rubbing
Ned	Adult	Male	Pounding
Temple Baggy	Adult	Male	Pounding / Rubbing
Temple	Adult	Male	Pounding
Logan	Adult	Male	Pounding
Mufy	Adult	Male	Pounding
Splash	Adult	Male	Rubbing
Awkward Cami	Adult	Male	Rubbing
Pinocchio	Adult	Male	Rubbing
Obelix	Adult	Male	Rubbing
Locke	Adult	Male	Rubbing
Lancelot	Adult	Male	Rubbing
DawsonT	Adult	Male	Rubbing
Lauren	Adult	Female	Forehead and gaze direction analysis
Perry	Young Adult	Male	Forehead and gaze direction analysis
Mary	Young Adult	Female	Forehead and gaze direction analysis
Scarface	Subadult	Male	Forehead and gaze direction analysis
MJ	Subadult	Male	Forehead and gaze direction analysis
David	Juvenile	Male	Forehead and gaze direction analysis
Talung	Juvenile	Female	Forehead and gaze direction analysis

Upie	Juvenile	Male	Forehead and gaze direction analysis