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RESEARCH ARTICLE

Effects of task complexity on grip-to-load coordination in bimanual actions

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Abstract We investigated within- and between-hand grip and load force coordination in healthy young subjects during bimanual tasks involving realistic manual actions. Actions involving disparate actions of the two hands (bimanual asymmetry) were expected to result in lower overall measures of within- and between-hand measures of grip and load force coordination. As dissociation between two hands performing disparate actions may be expected, it was also hypothesized that increased task asymmetry would result in a shift toward higher within-hand force coordination. Features such as object rotation were found to reduce some, but not all indices of both within- and between-hand force coordination. The action of connecting two independent objects was associated with declines in all indices of within- and between-hand force coordination. Evidence of task-specific differences in force application timing and a trend toward within-hand grip-load coordination differences in the current data set suggest that individual hand specification emerges naturally in everyday bimanual prehension tasks, independent of the action role of the assigned to the dominant and non-dominant hands.

Keywords Bimanual · Prehension · Coordination · Grasping forces · Rotation

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Introduction

Many activities of daily living (ADLs), such as opening containers or tying laces, require the limbs to complement each other in performing object-oriented tasks. The coordination of grasping and load-bearing force between the two hands is necessary in order to prevent unintended events such as slippage or rotation of the object(s) in any of the three dimensions. The tightly controlled relationship between grip and load force coordination in a variety of manual actions has been cited as a crucial aspect to preventing object slip by maintaining the safety margin in grasping (Augurelle et al. 2003; Flanagan et al. 1993; Flanagan and Wing 1993; Kinoshita et al. 1997). However, the tight coupling of grip and load force in manual actions has been found to be mitigated by age and neurological pathology (Blennerhassett et al. 2006; Dun et al. 2007; Fellows et al. 1998; Gorniak et al. 2011; Hermsdörfer et al. 2003). Initial work in this area has focused on grip-load coordination and mitigating factors in single-hand tasks (Flanagan et al. 1993; Flanagan and Wing 1993; Flanagan and Tresilian 1994; Tresilian 1999; Westling and Johansson 1984). Only recently has

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similar work been done in regard to grip-load coordination in bimanual prehension (Alberts et al. 1998, 2000; Obhi 2004).

While recent studies have begun to address bimanual tasks (Flanagan et al. 1999; Freitas et al. 2007; Freitas and Jaric 2009; Jin et al. 2011; Krishnan and Jaric 2010), the effect of task complexity as it relates to everyday actions has not been thoroughly assessed in bimanual grip-load coordination. For example, a variety of bimanual grasping techniques have been shown to provide appropriate grip-load force coordination between the hands (Flanagan et al. 1999; Freitas et al. 2007; Freitas and Jaric 2009; Jin et al. 2011; Krishnan and Jaric 2010) to maintain grasp of an object; however, the bimanual configurations tested do not translate well to everyday activities. Despite this limitation, increased task complexity (associated with task asymmetry) in bimanual configurations has been associated with deterioration in between-hand and within-hand force coordination in bimanual tasks (Krishnan and Jaric 2010), independent of hand dominance (Jin et al. 2011). Further, deterioration of force coordination contradicts recent results of strong between- and within-hand force coupling during the uni- and bimanual handling of fragile objects (Gorniak et al. 2009), yet compliments the general lack of hand dominance effects in bimanual tasks (Gorniak et al. 2007, 2008, 2009). Such discrepancies in reports of within-limb force coordination suggest more work is needed to understand what task factors affect both between- and within-limb coordination in bimanual tasks.

As previous studies presented very different prehensile tasks (applying oscillating grip forces to fixed objects versus lifting one fragile object), evaluating a task which requires grip-load coordination on two free-moving objects may disambiguate differences in kinetic patterns, particularly in realistic situations. Specifically, if the vertical load force applied to a freely moveable handheld object suddenly increases (with no other changes in either grip force or frictional conditions) then the object is at risk of slipping out of one's hand. If the same situation occurs during static grasp of a fixed object, the object is not at risk of slipping, it is still fixed (Flanagan et al. 1993; Flanagan and Tresilian 1994; Flanagan and Wing 1993). In fact, it is possible that subjects may create novel patterns of grip and load forces solely to perform such a given motor task on fixed objects.

In light of these issues, we developed a bimanual task to better replicate the types of manual activities performed on a daily basis. The task, similar to opening a jar, provides a method of assessing specific between- and within-hand patterns of grip-load force coordination. Given the previous findings, our aim is to determine whether between-hands coordination [an indicator of bimanual rescaling (Kelso et al. 1979)] or within-hand coordination (an indicator of hand specificity) is preferred when performing realistic bimanual tasks. During tasks in which the two hands perform highly asymmetric actions (such as object rotation), we expect higher indices of within-hand force coordination when compared to between-hand force coordination, indicating a shift toward hand specificity in bimanual tasks. We also expect that strong force coordination both between- and within-hand will diminish with increased task asymmetry (i.e., using rotational actions to connect two independent objects), as shown in previous evaluations of bimanual task complexity (Jin et al. 2011; Krishnan and Jaric 2010).

Methods

Participants

Twelve young healthy adults (seven male and five females) served as participants in this study. Average anthropometric data for the subjects were (mean ± SD): 27 ± 6 years of age, 1.72 ± 0.10 m in height, 73.7 ± 14.6 kg in mass. Handedness was assessed by the Edinburgh Inventory (Oldfield 1971), ranging from a laterality quotient (LQ) of −100 (which indicates strong left-handedness) to +100 (which indicates strong right-handedness). All subjects were strongly right-handed (LQ average = +93) and had no previous history of neuropathies or trauma to the upper limbs. All participants gave informed consent according to the procedures approved by the Institutional Review Board of the Cleveland Clinic.

Experimental setup and procedure

A system, illustrated in Fig. 1, was created to determine the fundamental time and force characteristics of a commonly performed bimanual task. The task involved connecting two independent objects together using one of two movements: (a) placing one object on top of another and (b) connecting the two objects by rotating the upper object while stabilizing the lower object. Grip (normal) and load (tangential) forces of both hands were recorded simultaneously using two identical six-component force–moment transducers (Mini 40 transducers; ATI Industrial Automation, Garner, NC, USA) during each bimanual manipulation task. One sensor was mounted in the "upper object," while the second sensor was mounted in the "lower object." The sensors were mounted vertically on individually customized aluminum housings. Two different articulation types (simple cylinder and a quarter-turn screw top referred to as *Non-Rotation* and *Rotation* tasks, respectively) between the two sensors were used throughout each testing session (see Panels B and C of Fig. 1). Within the customized housing,

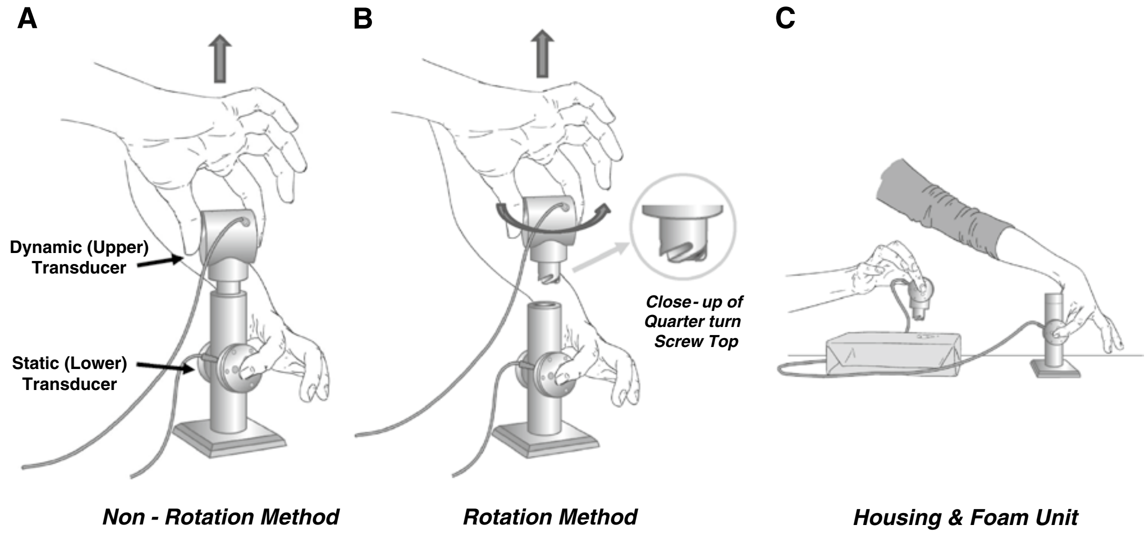

Fig. 1 Schematics of the bimanual tasks examined in this study. **a** An example of the task performed with the Non-Rotation method; static and dynamic transducers are indicated. **b** An example of the task performed with the Rotation method. A quarter-turn rotation in the counter-clockwise direction was required when performing tasks with the Rotation method, as shown in the magnified view of the articulation. **c** An example of the task performed with the Rotation method, including the foam containment unit. Note that participants performed the task with the device directly in front of them. The artist did not depict the actual subject location/position in this sketch

the center points of two of the Mini-40 sensors were spaced 0.09 m apart from each other. The grip width of the object (defined as the distance between the contact surfaces of the Mini-40 sensor and the contact surface of the sensor's aluminum housing) was 0.04 m. The total mass of the object was 0.680 kg (dynamic object mass = 0.223 kg, static object mass = 0.457 kg). The coefficient of friction between the conjoining surfaces of the transducer housings was minimized by using a silicon lubricant prior to testing in all conditions.

Participants were instructed to perform two different tasks for each articulation type, using only a pinch grip (thumb and index fingers only). Both the upper (dynamic) and lower (static) transducers were freely moveable objects; however, the location and orientation of the lower transducer was prescribed on the surface of a table at the onset of the experiment. Subjects were not permitted to move the static transducer during testing. The housing unit for the static transducer was significantly heavier than that of the dynamic transducer, thereby further discouraging movement of the static object (particularly lifting). Any trial in which movement of the static transducer occurred was omitted. Potential movement of the static transducer was vigilantly monitored by study personnel through the duration of each and every trial.

Overall, eight different bimanual configurations were tested in this experiment. Five trials were collected in each of the eight tested configurations (40 total trials in this experiment). Subjects were instructed to move in the following ways:

1. By using the right hand (RH) to connect (Connect) the dynamic transducer to the top of the static transducer using simple placement (Non-Rotation). The static object was stabilized on the table surface by the left hand (LH). The dynamic object was initially located 20 cm horizontally away from the static transducer (toward the right hand), positioned upright in a foam containment unit prior the onset of each trial.
2. Similar to action #1 with the exception that LH manipulated the dynamic transducer and the RH stabilized the static transducer. The dynamic transducer was initially located 20 cm horizontally away from the static transducer (toward LH), positioned upright in a foam containment unit prior to the onset of each trial.
3. By using the RH to disconnect (Disconnect) the dynamic transducer from the top of the static transducer using a simple pulling motion (Non-Rotation). The static object was stabilized on the table surface by the LH. As the housing components were made of aluminum and coated with a thin silicon lubricant, the coefficient of friction between the two objects in this condition was negligible. The end position of the dynamic transducer is the initial location described in action #1.
4. Similar to action #3 with the exception that LH manipulated the dynamic transducer and the RH stabilized the static transducer. The end position of the dynamic transducer is the initial location described in action #2.
5. By using the RH to connect (Connect) the dynamic transducer from the top of the static transducer using quarter-turn rotational action (Rotation). The static

object was stabilized on the table surface by the LH. The initial position of the dynamic transducer is the same location described in action #1.

6. Similar to action #5 with the exception that LH manipulated the dynamic transducer and the RH stabilized the static transducer. The initial position of the dynamic transducer is the same location described in action #2.
7. By using the RH to disconnect (Disconnect) the dynamic transducer from the top of the static transducer using quarter-turn rotational action (Rotation). The static object was stabilized on the table surface by the LH. The end position of the dynamic transducer is the initial location described in action #1.
8. Similar to action #7 with the exception that LH manipulated the dynamic transducer and the RH stabilized the static transducer. The end position of the dynamic transducer is the initial location described in action #2.

No contact of either transducer was permitted prior to trial onset; subjects were instructed to begin each trial with both hands placed palm down on the surface of the table. Up to three practice trials were offered to each subject prior to the onset of data collection for each condition. On average, each subject performed one practice trial prior to the onset of data collection for a given condition. The presentation of the eight testing condition was block randomized.

Data analysis

Transducer signals were amplified and multiplexed using a customized conditioning box (from ATI Industrial Automation, Garner, NC, USA) prior to being routed to a 16-bit analog to digital converter (PCI-6036E, National Instruments, Austin, TX, USA). A customized Labview program (National Instruments, Austin, TX, USA) was used for data acquisition, and customized MATLAB (Mathworks Inc., Natick, MA, USA) programs were written for data processing. Signals were sampled at 256 Hz. The force data were low-pass filtered at 6 Hz using a 2nd order zero-lag Butterworth filter. Force (application) onset and termination were determined as functions of the largest grip forces applied to the transducers. Force onset was defined as the earliest time of 3 % maximal grip force application prior to the time point of actual maximal grip between the two transducers, within a trial. Force termination was defined as the time of 3 % maximal grip force application after the time point of actual maximal grip of the dynamic transducer. Similar methods were reported in kinetic hand studies (Gorniak et al. 2009; Zhang et al. 2009). Initial analysis of the data presented in this manuscript revealed more consistent force trajectories using the 3 % threshold of maximum grip when compared to the 5 % threshold of the max derivatives outlined in the previously referenced work. Task time was defined as the period between force onset and force termination. All force data were time normalized with respect to task time (expressed as 0–100 % of task time) via cubic splines.

Temporal analysis

Three measures of timing were calculated for this study. Task time, grip delay, and load delay were calculated based on averaged data for each subject in each condition. Averaged data were calculated across the individual trials after time normalization, aligned by grip force onset (see previous paragraph). Task time and both of the delays are reported in seconds (s). Task time was defined as the time between grip force onset and termination. Grip delay is defined as the difference between the onsets of grip forces between the two transducers; a positive value indicates that the static transducer was contacted initially, while a negative value indicates that the dynamic transducer was contacted initially. Load delay was defined similarly to grip delay, but with respect to load force application.

Kinetic analysis

Grip and load forces were analyzed in terms of total load force and total grip force. The forces were calculated as twice the measured value of each force, respectively. This calculation was used as only two force–torque sensors were available for use in the experimental setup (one embedded in the dynamic housing, the other embedded in the static housing). Beyond general force profiles, four correlation coefficients were calculated.

1. Between-hands grip force correlation (*rGrip*) was calculated as the correlation coefficient between the total grip force exerted on the dynamic transducer and the total grip force exerted on the static transducer.
2. Similarly, between-hands load force correlation (*rLoad*) was calculated as the correlation coefficient between the absolute value of total load force exerted on the dynamic transducer and the absolute value of total load force exerted on the static transducer. Absolute values of exerted load forces were used to be consistent with values presented by Jaric and colleagues (Jin et al. 2011; Krishnan and Jaric 2010).
3. The within-hand grip-load force correlation for forces exerted by the static hand (rGL_S) was calculated as the correlation between the total exerted grip force and the total exerted load force recorded by the static transducer.
4. Lastly, the within-hand grip-load force correlation for forces exerted by the dynamic hand (rGL_D) was calculated as the correlation between the total exerted grip force and the total exerted load force recorded by the dynamic transducer.

Correlation coefficients were calculated as the overall correlation between the named variables across the entire time normalized interval (0–100 %) for each of the five trials in each of the tested conditions. Cross-correlation of the force profiles revealed maximal correlation values at time lag of 0 ms; thus, all correlations were performed using a zero-lag delay.

Statistics

The data are presented in the text and figures as means ± standard errors. Repeated measures analyses of variance (RM-ANOVAs) were performed on the force data with the factors of: *Method* (two levels to describe the action used; Rotation and Non-Rotation), *Task* (two levels to describe the overall goal of the task; Connect and Disconnect), and *Upper Hand* (two levels to describe the hand used to move the dynamic transducer; Right and Left). An additional factor of *CorrType* (four levels; rGL_S, rGL_D, *rGrip*, and *rLoad*) was used to compare the values of the correlation coefficients calculated in this study. Subscripts S and D refer to the within-hand correlation values for the static and dynamic transducers, respectively. Correlation coefficient (r) values from the regression analyses were subjected to Fisher's z-transformation to mitigate the ceiling effects inherent to these variables. Non-transformed data are presented in the figures to avoid confusion. To analyze differences between the measures recorded independently by the two transducers in the setup for the *rGL* measures, a between-subjects factor of *Transducer* was used (two levels to represent the two transducers within the setup, static and dynamic). Similar to the force data, RM-ANOVA was performed for the time-delay data, except a factor of *DelayType* (two levels, *Grip* and *Load*) was used instead of *CorrType*. For all ANOVAs, the assumption of sphericity was verified using Mauchly's sphericity test. If sphericity was violated, the degrees of freedom were adjusted as necessary using Greenhouse–Geisser corrections.

Results

Task performance

Typical force profiles were smooth and continuous for all tasks performed in this study. An example of typical force profiles in each of the four tasks can be found in Fig. 2. In non-rotational actions, grip forces occurred at a maximum around 35 % of the total movement time. In contrast, during rotational actions, the maximum grip forces occurred later (nearly 50 % of movement time). The magnitudes of the forces exerted on the dynamic transducer were generally larger than those exerted on the static transducer.

Timing

The overall time to perform the task (task time) was affected by the *Task* and *Method* used by subjects. Task time was greater when the two objects were being connected to each other (by 27 %; *Task* $F_{1,11} = 116.3$, $p < 0.001$) and during rotational actions (by 16 %; *Method* $F_{1,11} = 12.2$, $p < 0.005$). While task time increased when the two objects were being connected together, this effect was particularly larger when rotational actions were used (*Task* × *Method* $F_{1,11} = 19.2$, $p < 0.001$). An illustration of the *Task* × *Method* interaction for task time can be found in Fig. 3a.

The difference in timing of force onset between the two transducers was primarily affected by task type (*Task* $F_{1,11} = 23.0$, $p < 0.001$), but not the type of force (grip vs. load), shown in Fig. 3b. In trials in which the two objects were disconnected from each other, the force onset delays were positive, indicating the stabilizing hand contacted its respective transducer first. In contrast, in trials in which the two objects were connected to each other, the force onset delays were negative, indicating the dynamic hand performed the initial contact.

Kinetics

Within-hand (rGL_S and rGL_D) and between-hand (*rGrip* and *rLoad*) force correlations were calculated for the four conditions tested in this experiment. While no difference was found between the between-hand grip coordination (*rGrip*) and both values of within-hand grip-load coordination (rGL_S and rGL_D), the between-hand load force coordination (*rLoad*) was significantly lower than the other three correlation values (*CorrType* $F_{3,33} = 17.8$, $p < 0.001$) across all tested conditions, verified with post hoc analysis ($\alpha = 0.05$, $n = 3$, $p < 0.017$), shown in Panels A and B of Fig. 4. A trend toward higher within-hand correlations for the static hand (rGL_S) when compared to the dynamic hand (rGL_D) was noted, but not significant ($p = 0.1$). Beyond these differences, each correlation coefficient was affected by *Task* ($F_{1,33} = 10.8$, $p < 0.001$), shown in Panel A of Fig. 4, such that Connect-type tasks were associated with lower overall correlation coefficients, when compared to Disconnect-type tasks. Conditions that involved object rotation were mildly associated with lower correlation coefficients when compared to Non-Rotation tasks, this trend did not reach statistically significance (*Method* $F_{1,33} = 4.1$, $p = 0.07$). An interaction of *CorrType* and *Method* was found (*CorrType* × *Method* $F_{3,33} = 9.6$, $p < 0.001$), indicating that rotation was associated in a decrease in force correlation values, but only in the case of between-hand load coordination (*rLoad*) and within-hand grip-load coordination for the dynamic hand (rGL_D), shown in Panel B of Fig. 4 (noted by the symbol ‡).

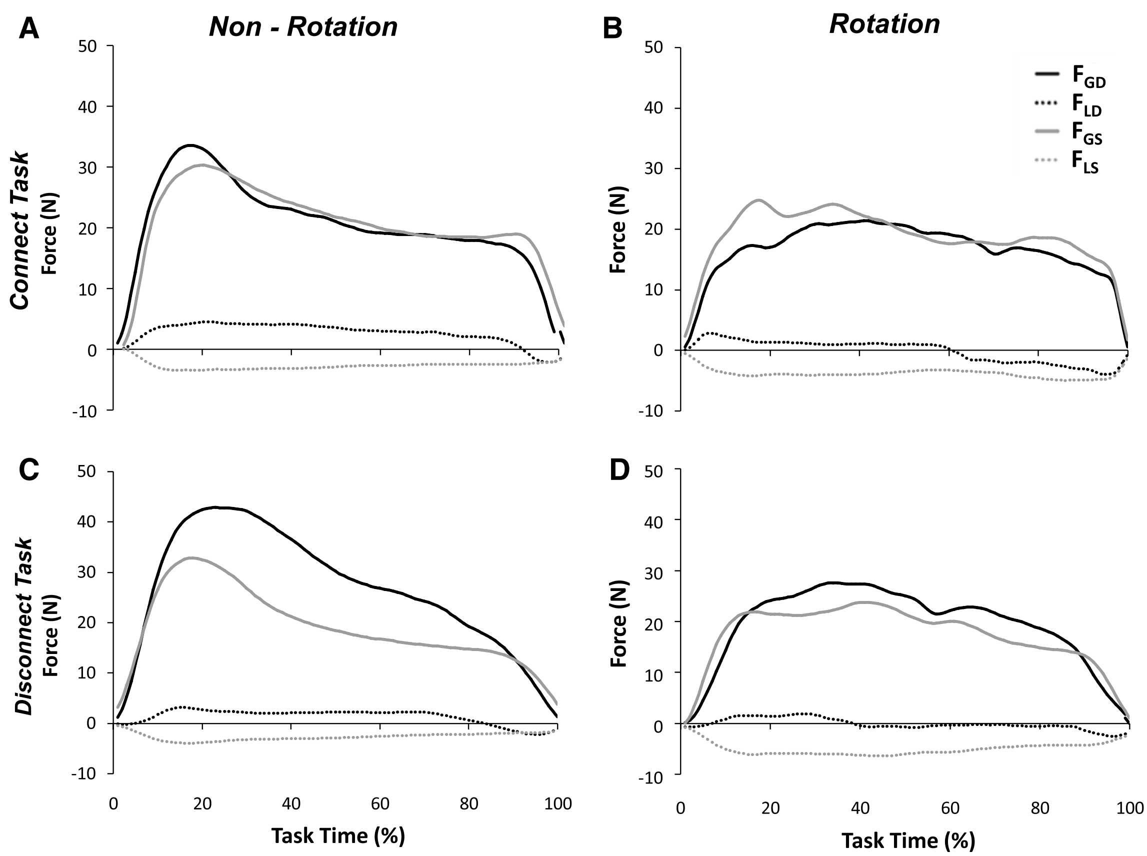

Fig. 2 Average grip and load force profiles exerted of a typical subject in each of the four tasks examined with respect to movement time. Grip and load forces exerted on the dynamic (*upper*) transducer are denoted by F_{GD} and F_{LD}, respectively. Grip and load forces exerted on the static (*lower*) transducer are denoted by F_{GS} and F_{LS}, respectively. **a** Total grip and load forces exerted when the two transducers were connected without rotation. **b** Total grip and load forces exerted when the two transducers were connected using rotation. **c** Total grip and load forces exerted when the two transducers were separated without rotation. **d** Total grip and load forces exerted when the two transducers were separated using rotation

Lastly, no main effects of *Upper Hand* (right vs. left differences) were found in any of the temporal or kinetic measures ($p > 0.3$ for all ANOVAs).

Discussion

Within the current study, we explored the effect of task complexity on grip and load force coordination in an ecological bimanual task. Here, increased grip-load correlations are viewed as beneficial in maintaining adequate safety margin for handheld objects. Our data partially support our hypothesis, as connecting two independent objects (a highly asymmetric task) was generally associated with decreases in all forms of grip and load force coordination, for both within-hand and between-hand coordination measures. The addition of rotational action into the tested conditions did affect measures both of between- and of within-hand coordination (namely *rLoad* and rGL_D). Overall, a trend toward hand specificity in bimanual tasks was found, but was not statistically significant in the current study. No effect of hand dominance was found in any of the examined measures. In the following paragraphs, we discuss our findings in terms of within- versus between-hand coordination, task complexity, and handedness.

Within- versus between-limb coordination

Given the frequency of bimanual tasks completed daily, the hands must work together in a coordinated manner to achieve common motor goals. Frequently, the hands are involved in complementary tasks, such that one hand acts as a stabilizer, while the other hand acts dynamically to manipulate an object (Alberts et al. 1998; Sainburg 2002, 2005). Early investigations into the relationship between the hands in such tasks suggest that between-hand dependencies do exist, particularly with respect to the spatial and temporal aspects of bimanual tasks (Obhi 2004; Serrien and Wiesendanger 2001a, b). Such synchronization has been interpreted as evidence of global organization of bimanual activities within

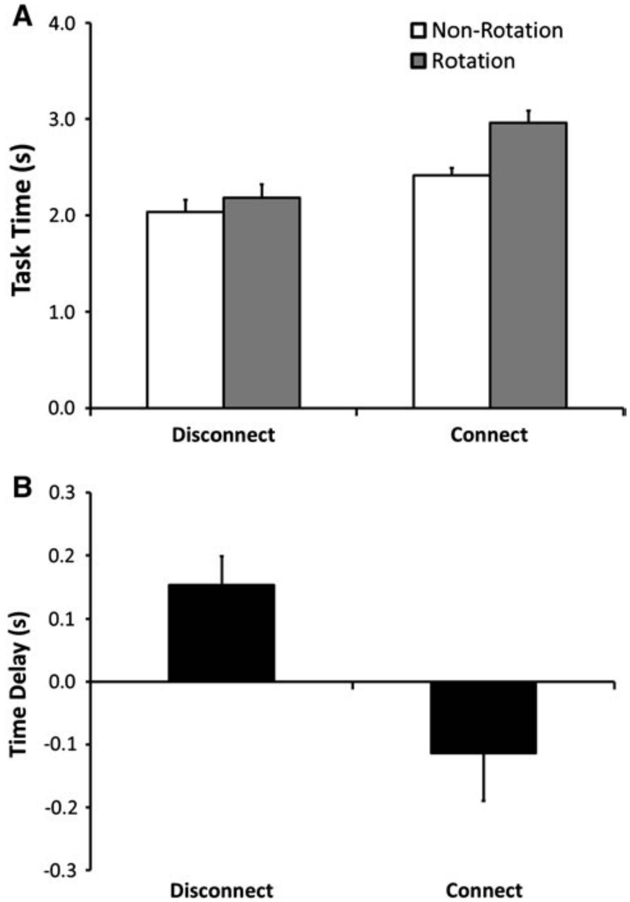

Fig. 3 Mean and standard error of task time and force application delays. Timing data are shown for Disconnect and Connect tasks. **a** Task time during Rotational and Non-Rotational actions. **b** Averaged values of force application delays

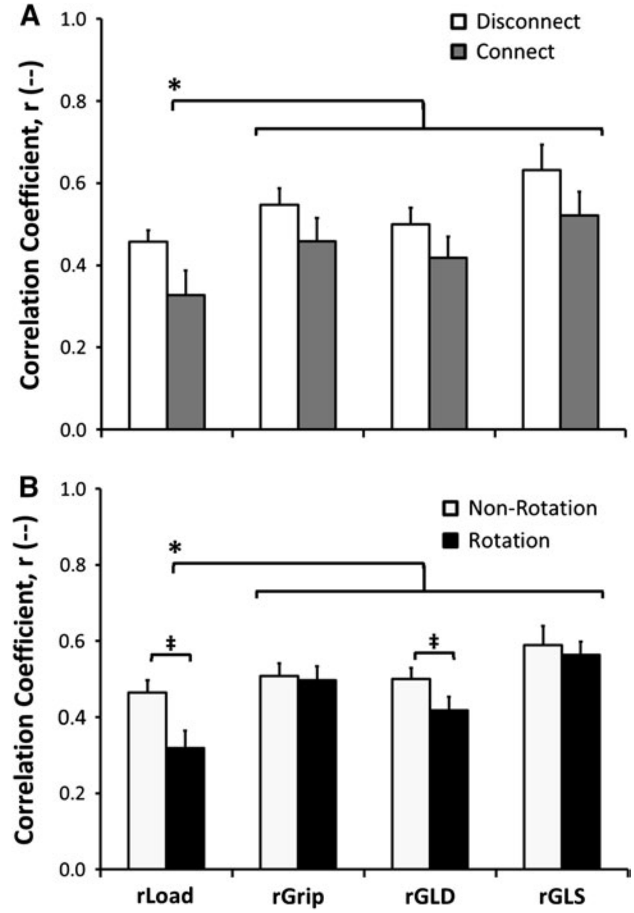

Fig. 4 Mean and standard error of the within-hand (rGL_S and rGL_D) and between-hand (*rLoad* and *rGrip*) correlation coefficients. The value of *rLoad* was significantly less than each of the other three correlation coefficients (*). **a** Correlation coefficients in the Connect- and Disconnect-type tasks (averaged across *Method*). **b** Correlation coefficients in the Non-Rotation and Rotation method tasks (averaged across *Task*). Significant differences in the correlation coefficients between the Non-Rotation and Rotation conditions for *rLoad* and rGL_D were found (‡)

the CNS. In contrast, recent theories advocating individual specification and local organization of each hand within the CNS have emerged (Sainburg 2002, 2005; White et al. 2008). Specially, it has been proposed that differing hand goals (such as dynamic action vs. static holding) may induce flexible coordinative constraints between the two hands, allowing for grip-load dissociation between the two hands in complex bimanual tasks.

Given the task-specific differences in force application timing and a trend toward within-hand grip-load coordination differences in the current data set, it is likely that individual hand specification emerges naturally in everyday bimanual prehension tasks. Specifically, the timing delays in grip and load force application are evidence of a complementary dissociation between the hands as a means to perform a complex action. It is most likely that these differences in action were anticipated in the planning stages of movement, consistent with reports of altered hand kinematics due to changes in object properties and intended actions (Eastough and Edwards 2006; Jackson et al. 2002).

Differences in between-hand grip and load force coordination for the two hands in a bimanual task also reflect complementary dissociation between the two hands during asymmetric actions, similar to earlier reports of flexible coordinative constraints between hands involved in disparate actions (Krishnan and Jaric 2010). The trend toward reduction in grip-load coordination in the dynamic hand in bimanual tasks suggests that documented high levels of feed-forward grip force coordination deteriorate during more complex bimanual actions (Flanagan et al. 1993; Flanagan and Tresilian 1994; Flanagan and Wing 1993; Krishnan and Jaric 2010).

Additionally, lower correlation between absolute load forces exerted on the two objects in this study suggests that between-hand organization of hand action can be mitigated by differing motor goals of the two hands. Given the trend in within-hand grip-load force correlations, as well as differences in between-hand force scaling across tasks, the notion of individual hand specification is mostly supported in bimanual tasks. While these results suggest local organization of hand action, they are contradictory to classical views of globally organized bimanual action [e.g., (Kelso et al. 1979)]. While the functional grouping of muscles to perform bilateral actions is not under question, we propose that similarities between the limbs deteriorate as the motor goals of the two hands become disparate. The current study is one of the first attempts to examine truly disparate yet complementary actions of two hands in a meaningful bimanual prehension task, in contrast to previous kinematic studies of bimanual action (Kelso et al. 1979; Mason and Bryden 2007, 2009). Further, we suspect that such disparity will be further pronounced in evaluating complex bimanual tasks in individuals with lateralized movement disorders due to impaired control of manual actions (Rice and Newell 2004).

Effects of task complexity

When performing activities of daily living, many situations require both hands to be used in a complementary way by separating two objects. In this light, removing an object by manual rotation is a common occurrence in everyday actions, such as opening a jar. In the current manuscript, we evaluate how actions such as Rotation (vs. Non-Rotation) and the direction of the task (connecting two objects vs. disconnecting them) affected basic features of manual prehension. While the bulk of literature points to varying combinations of feed-forward and feedback control of most manual tasks (Flanagan and Tresilian 1994; Serrien et al. 2000; Weiss and Jeannerod 1998), the increased precision constraints of the rotational and connection-type tasks likely shifted the CNS into using more sensory feedback to complete the bimanual action. Both the action of rotation and of connecting two objects were associated with increased task time and overall decreases in both between- and within-hand grip-load coordination. The integration of additional information from limb proprioception, slowly adapting type 1, and rapidly adapting mechanoreceptors of the fingertips (Johansson and Westling 1987) all likely contribute to the increased time needed for task completion in rotational actions. Additionally, it is likely that both tactile and visual information were used by subjects to complete Connect-type tasks, consistent with informal comments made by participants in the current study. Future studies focusing on altering and/or removing the sensory feedback during bimanual tasks is needed to help clarify which of the feedback types were the dominant contributor to these behavioral changes. We acknowledge that there may be slight decreases in the correlation values due to de-synchronization occurring in tasks requiring more feedback; however, further investigation into both timing and availability of sensory feedback is needed to disambiguate such a relationship.

Effects of handedness on bimanual actions

While evidence has emerged regarding hand specification as the result of lateralized hemispheric specialization (Sainburg 2002, 2005), laterality-based differences in manual hand action have not been corroborated in measurements of hand and finger forces (Gorniak et al. 2007, 2008, 2009; Jin et al. 2011). Within the current study, no differences were found with respect to laterality (use of the dominant vs. non-dominant hand) in either the action of the dynamic and static aspects of the tested bimanual tasks. While the dominant hand may be preferred for dynamic reaching tasks (Sainburg 2002, 2005), this hand specificity does not appear to transfer to force production tasks. Rather, it appears as though the context in which the hand acts is more important than the hemisphere to which it is associated. Further work is needed in this area to clarify the extent to which lateralized hemispheric specialization affects manual actions.

Conclusions

Based on the results of the current study, we conclude that individual specification of kinetic and kinematic components of movement occurs for each of the hands in a bimanual task, independent of the action role of the assigned to the dominant and non-dominant hands. Further work is needed to disambiguate the roles of visual and proprioceptive feedback in the deterioration of within-limb grip-load coordination in complex bimanual tasks.

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