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It's Not What You Do Its the Way That You Do It: the Influence of Obesity on the Speed and Accuracy of a Discrete Aiming Task

David Gaul
Technological University Dublin, david.gaul@tudublin.ie

Laure Fernandez
Aix-Marseill Université

Johann Issartel
Aix-Marseille Université

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Title: "It's not what you do its the way that you do it": The influence of obesity on the speed and accuracy of a discrete aiming task.

David Gaul[1], Laure Fernandez[2], and Johann Issartel[1].

[1]School of Health and Human Performance, Dublin City University, Dublin, Ireland.

[2] Aix-Marseille Université, CNRS, ISM UMR 7287, 13288, Marseille, France

Corresponding Author: David Gaul

Corresponding Author's Institution: Dublin City University

Corresponding Author's Telephone: 01 700 7441

Corresponding Author's Email Address: david.gaul2@mail.dcu.ie

Corresponding Author's Postal Address: School of Health and Human Performance, Dublin City University, Dublin 9. Ireland.

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Introduction

Obesity is a major public health concern which is linked with increased risk of cardiovascular disease, stroke, cancer, type 2 diabetes, hypertension, depression and obstructive sleep apnea (OSA) (Lee et al. 2012). Overweight and obesity levels have reached epidemic levels. According to World Health Organization (WHO) figures from 2014, 39% of men and 40% of women aged 18+ were overweight (OW) (BMI >25kg/m2) and 11% of men and 15% of women being obese (OB) (BMI >30kg/m2) (World Health Orgainisation 2014). This equates to almost 2.5billion adults being overweight or obese worldwide. The rate of growth is another concern with the prevalence of obesity growing worldwide from 3% and 6% in men and women respectively in 1975 to 11% in men and 15% in women in 2014 (World Health Orgainisation 2014). Knecht et al (2008) referred to the obesity as being "considered a problem of the belly rather than of the brain" however they pointed to evidence of a number of neurobiological factors related to obesity. There are a large number of studies that have found a relationship between obesity and various facets of cognitive function (See Prickett et al (2014) for review). A recent study by Bove et al (2016) found associations between adiposity and visuospatial skills and memory in otherwise healthy young men with abdominal adiposity. Gunstad et al (2007) found obesity to be linked to reduced cognitive function, specifically in terms of executive function. A large scale cross-sectional study found that overweight and obese participations performed poorer on neuropsychological tests than their counterparts with a BMI<25kg/m^2 (Benito-Leon et al. 2013). Another study by Segura et al (2009) also found significant differences between participants with Metabolic Syndrome (92.7% of whom were OB) and normal weight (NW) controls in a number of components of cognitive function including slowness in mental processing and executive dysfunction. Further to this, a number of studies have linked obesity to neurodegenerative diseases such as Alzheimer's Disease (AD) and Dementia (Kivipelto et al. 2005). Reviews by Bedoun et al (2008) and Crichton et al (2012) have shown the associations between being OW and OB and increased risk of developing AD and Dementia. A longitudinal study by Whitmer et al (2005) indicated that the risk of dementia was increased by 74% among OB participants at baseline and by 35% for OW participants at baseline. The reason behind this relationship is poorly understood with evidence suggesting hormone activity, structural changes and brain inflammation as potential causes (Prickett et al. 2014). However there is currently insufficient evidence to determine whether relative cognitive dysfunction contributes to excess weight gain or whether obesity causes this cognitive dysfunction (Bove et al. 2016). A longitudinal study by Chandola et al (2006) suggested that reduced cognitive function in childhood could increase the risk of becoming OW or OB.

In addition to executive function, attention and other components of cognitive function, obesity has been linked with impaired motor function (Liang et al. 2014; Wang et al. 2016). In children, being OB or OW has been found to result in poorer gross and fine motor skill, fundamental movement skill and delayed motor development (Mond et al. 2007; Cawley and Spiess 2008; Poulsen et al. 2011; Gentier et al. 2013). However a number of studies evaluating cognitive function have found reduced psychomotor and processing speed in OB and OW individuals (Cournot et al. 2006; Gunstad et al.

2007; Cserjési et al. 2009; Fergenbaum et al. 2009; Stanek et al. 2013). A study by Cournot et al (2006) found slower processing speed and poorer attention in participants with a higher BMI. Traditionally obesity has been seen to impair the successful completion of these activities due to the mechanical constraints of excess mass. However research has begun to highlight the potential presence of perceptual motor coordination difficulties in OB individuals (Petrolini et al. 1995; Bernard et al. 2003; D'Hondt et al. 2008; Osika and Montgomery 2008; D'Hondt et al. 2009; D'Hondt et al. 2011; Gentier et al. 2013). As the excess mass associated with obesity has limited mechanical constraints on fine motor skills, this suggests an underlying motor control problem in the processing and integration of information (Gentier et al. 2013). A number of studies in other fields have found that altered sensory integration in obese individuals (Wan et al. 2014; Scarpina et al. 2016). A recent study by Gaul et al (2016) suggested that obesity affects the sensory integration process in a motor task. This study found morbidly OB adults demonstrated significantly poorer performance during a visual motor synchronisation task when compared to a healthy weight control group (Gaul et al. 2016). The presence of motor control and coordination problems have been extensively reported in difficulties in a number of special populations such as Cerebral Palsy (Himmelmann et al. 2006), Attention-deficit-hyperactivity-disorder (ADHD) (Flapper et al. 2006), Developmental Coordination Disorder (DCD) (Piek and Dyck 2004), Autism (Matson et al. 2011; Liu and Breslin 2013), Parkinson's (Bienkiewicz and Craig 2015) and Schizophrenia (Varlet et al. 2012). The breath of studies showing motor control problems in special populations emphasizes the link between motor skill and executive processes. Interestingly, for many of these special populations, increased BMI or obesity is frequently a comorbidity (Gillberg et al. 2004; Matson et al. 2011; Hendrix et al. 2014). This would suggest that obesity influences the processes underlying motor control and the coordination of movement. As such, this study sought to evaluate the influence of obesity on the motor control process.

Following on from Woodworth's (1899) ground breaking work over a century ago, we still use his two component model to help gather empirical evidence on modern research questions (Elliott et al. 2001). The successful completion of reaching and grasping actions requires the ability to appropriately coordinate the speed and accuracy of such movements. This trade-off between movement speed and accuracy is known as 'Fitts' law', which is defined by a linear increase of movement time with the increased difficulty of an aiming task (Fitts, 1954, see Meyer, et al., 1988 and Plamondon & Alimi, 1997, for reviews). As such, difficulties in the integration and performance of goal directed reaching tasks could impair the effective performance of many activities of daily living such as brushing ones hair, feeding oneself or picking up items (Kirby et al. 2011). For example Parkinson's suffers frequently experience difficulties in the performance of everyday actions such as walking, dressing oneself, handwriting or using a computer mouse as a result of their motor control problems (Stoffers et al. 2002). As obesity is already known to negatively impact individual's quality of life and influence performance of activities of daily living (ADL) as a result of the mechanical consequence of excess weight, any such motor control difficulties could increase the difficulty of everyday tasks (Rosmond and Bjorntorp 2000). This study employed a discrete version of the Fitt's task in order to measure the "pure movement" execution rather than the inherited error from the previous movement in the reciprocal Fitt's task (Guiard and Olafsdottir 2011). This study aimed to conduct a discrete version of a Fitt's task paradigm using a digital tablet. We intended to determine whether being overweight or obese altered participants speed and accuracy during an aiming task. A secondary hypothesis was to determine whether manipulation of tablet orientation increased task difficulty. In order to carry out a Fitt's task when the tablet was in a vertical orientation, participants were required to hold their arm and hand in an upright position. This requires greater muscle activation and as such requires great time demands in order to implement thus resulting in increased movement time (Gribble 2003; Fernandez and Bootsma 2004; Loeches De La Fuente et al. 2014) and novel movement organisation that would differ between obese, overweight and normal weight participants.

Methods

Participants

A total number of 183 (see Table 1) participants partook in this study as part of an interactive exhibition at a science gallery. All participants had their height, weight and body fat measured and BMI calculated prior to participation. This data was used to divided participants into weight categories based on their Body Mass Index(kg/m^2)(BMI).

Apparatus and Task

Participants were seated comfortably at a table, facing graphics tablet (Wacom Ultra Pad A3) placed in both horizontally and vertical positions mounted on a custom rotating stand on the table in front of them. Left-right motion of a hand-held stylus displaced a cursor on the tablet screen via ICE software developed by Marseille University Lab. The task was to move the cursor, represented by a red vertical line spanning the full height of the tablet, between two targets depicted on the screen as fast and as accurately as possible (i.e. Fitts task). The target was a rectangle of a given width at a given distance (depending on the Index of Difficulty (ID)) with a height corresponding to the height of the screen. Movement was recorded along both horizontal and vertical axis; analysis focused solely on movement along the X-axis. The position of the stylus on the graphics tablet was sampled at a frequency of 150 Hz.

Recordings and Procedure

A session consisted of 64 discrete aiming movements from one target to the other in 2 different orientations (32 Horizontal and 32 Vertical). The were 4 separate experimental conditions made up of a combination of 2 different target width (Close and Far) and two distances (Short and Long). This led to participants performing at four levels of task difficulty: ID = 3.22, 4.73, 5.23 and 6.64 with $ID = \log_2 (2D/W)$ (Fitts, 1954). During the experiment, the participants carried out the 4 Blocks of 8 trials (4 conditions x 2 repetitions) in both Horizontal and Vertical orientations. As such, the experiment consisted of one testing session of the following design: 2 Tablet orientations X 4 Blocks X 4 Conditions X 2 repetitions of each condition. The order of trials was randomized across all blocks and the order of which orientation was displayed first was counterbalanced across all participants to remove any order effects. Errors were defined as an overshoot, i.e. movement beyond the external edge of the target outside area. In an event of an undershoot, the trial would continue until the cursor reached the target. A familiarization phase was included at the beginning of both sessions. The first trial for each condition in each block in addition to all familiarization trials were not analysed to avoid transient behaviour in the analysis.

Data analysis

The position time series were filtered with a dual-pass, second-order Butterworth filter, using a 8 Hz cut off frequency. Velocity and acceleration were subsequently derived using a 3-point central difference technique. The analysis focused on movement time, percentage of overshoot, peak velocity, peak acceleration and percentage of acceleration time. In order to evaluate the influence of tablet Orientation, differences for each variable were calculated by subtracting values for horizontal orientation from vertical orientation. The first two trials and last trial for each condition were removed from the analysis to eliminate any learning effects. For each session, measures were averaged across the remaining 5 trials for each of the 4 conditions. For each trial, movement time (*MT*) was defined as the time taken from movement initiation (when 5% of PV was reached) to entry of the opposite target (Missenard and Fernandez 2011). Percentage Overshoot was calculated by determining the number of trials that the participant moved beyond the external edge of the target and dividing it by total number of trials.

Statistical analysis

Repeated-measures ANOVAs were performed between groups (OB, OW and NW), Orientation (Vertical and Horizontal), Target Width (Small and Large) and Target Distance (Close and Far) as factors. Sphericity was assessed for each dependent variable and the Greenhouse–Geisser's correction was applied when sphericity was not met. Post hoc analysis using Bonferroni's correction was used in order to detail significant effects. Statistical significance was set a $p<0.05$.

	Normal Weight	Overweight	Obese	Total
N	107 (58.5%)	58 (31.7%)	18 (9.8%)	183 (100%)
M/F	37/70	33/25	7/11	77/106
Age (yrs)	34.18 ± 14.09	38.97 ± 14.42	41.72 ±16.55	36.44 ± 14.63
Weight (kg)	63.34 ± 8.17	79.90 ± 10.20	100.73 ± 16.81	72.26 ± 15.60
Height (cm)	170.56 ± 8.52	172.36 ± 10.12	170.94 ± 9.84	171.17 ± 9.17
BMI (kg/m^2)	21.72 ±1.77	26.79 ± 1.36	34.34 ± 4.00	24.57 ± 4.44

Table 1: Descriptive Statistics shown for participants divided by weight category.

Results

Movement Time

A 2 (Orientation) x 2 (Width) x 2 (Distance) x 3(Participant Group) repeated measures ANOVA was carried out on movement time scores for participants. There was a significant interaction effect found between tablet orientation and target width. $F(1,180)=5.51$, $p<0.05$. Post hoc tests revealed that participants movement time was significantly greater for vertical orientation (M=.83 SE=.04, 95% CI [.76, .91]) compared to in a horizontal orientation (M=.73 SE=.04, 95% CI [.67, .79]) when the target was small. Post hoc tests also revealed significantly greater movement time for vertical orientation (M=.72 SE=.03, 95% CI [.66, .78]) compared to horizontal orientation (M=.66 SE=.03, 95% CI [.61, .72]) when the target was large. There was also a significant main effect found for target distance $F(1,180)=143.68$, $p<0.01$, with all participants having greater movement times when the target was further away (M=.83, SE=.03, 95% CI [.76, .89]) compared to the closer target distance (M=.65 SE=.03, 95% CI [.60, .70]) There was no significant main effect found for group $F(2,180)=1.08$ $p<0.05$.

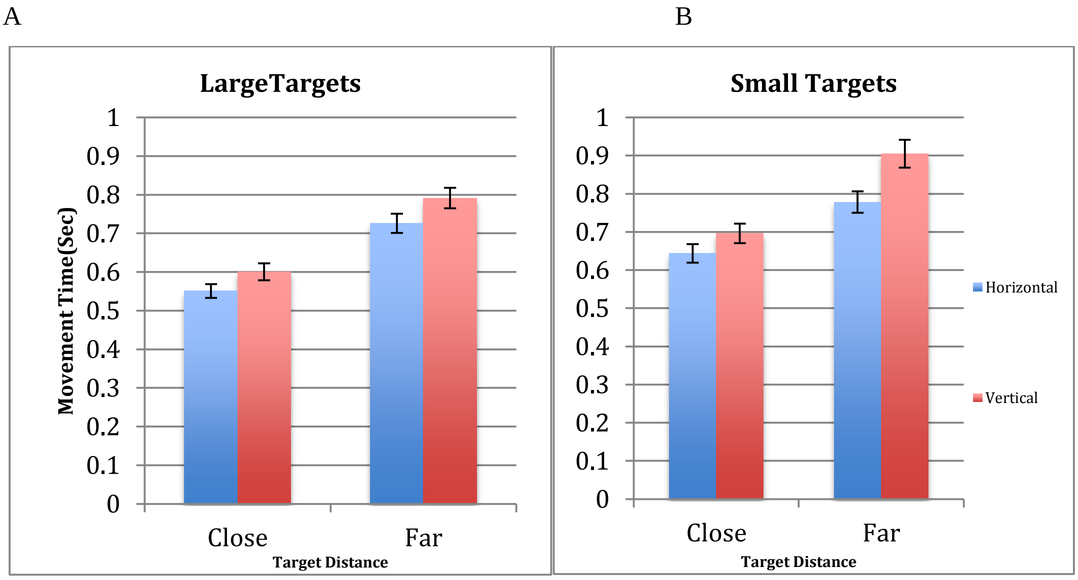

Figure 1: Participant Movement Times for all 4 conditions divided by Horizontal and Vertical Tablet Orientations.

Peak Acceleration

There was a significant interaction effect found between orientation and participant group, $F(2,180)=3.63$, $p<0.05$. Post hoc tests revealed that the obese individuals had significantly higher values for horizontal conditions (M=624.73 SE=90.76, 95% CI [445.63, 803.82]) compared to vertical conditions (M=451.19 SE=88.87, 95% CI [275.83, 626.55]) when compared to their NW (M=499.57 SE=37.23 95% CI [426.12, 573.03] and M=530.12 SE=36.45, 95% CI [458.2, 602.04]) and OW (M=499.35 SE=50.56 95% CI [399.58, 599.13] and M=486.89 SE=49.51 95% CI [389.2, 584.58]) peers respectively. There was also a significant interaction effect found between distance and orientation, $F(1,180)=5.92$, $p<0.05$. Following post hoc analysis it was revealed that there was a significantly higher values for peak acceleration in horizontal orientation (M=696.43 SE=55.6, 95% CI

[586.73, 806.14]) compared to vertical orientation (M=603.05 SE=53.07, 95% CI [498.32, 707.78]) when the targets where far away. There was also significant main effects found for target width F(1,180)=4.33, p<0.05, with participants demonstrating greater peak acceleration values for large targets (M=522.21 SE=34.69, 95% CI [453.76, 590.66]) compared to smaller targets (M=508.41 SE=32.58, 95% CI [444.12, 572.71]).

A B

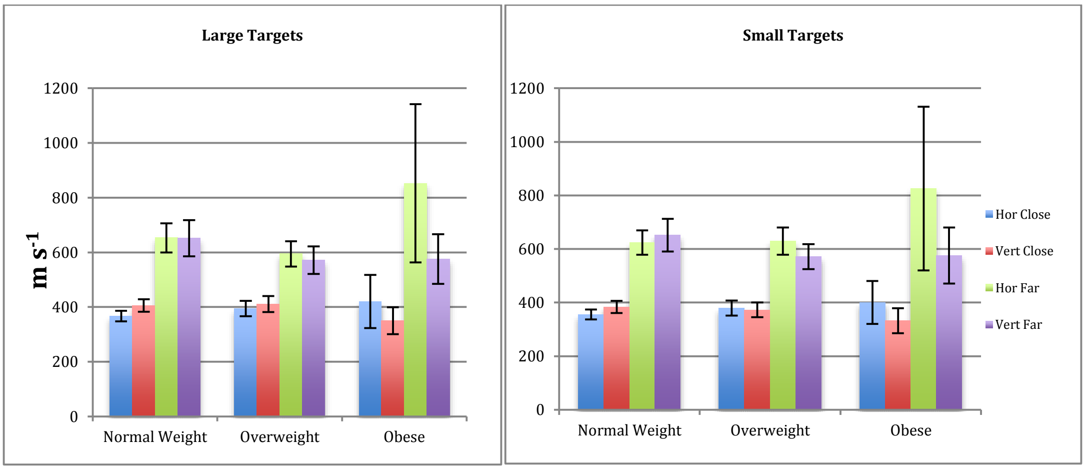

Figure 2: Peak Acceleration Values shown for NW, OW and OB participant groups when the target width was Large (A) and Small (B) in both horizontal and vertical conditions.

Peak Velocity

There was a significant interaction effect found between tablet orientation and target distance, F(1,180)=21.98, p<.01. Post hoc tests revealed significantly higher peak velocities for the horizontal orientation (M=120.05 SE=4.58, 95% CI [111.02, 129.08] compared to vertical orientation (M=108.52 SE=4.41, 95% CI [99.82, 117.22]) when the target was further away. There was also a significant main effect found for target width F(1,180)=21.49, p<0.01, with higher peak velocities for large targets (M=86.37 SE=2.96, 95% CI [80.53, 92.21]) compared to small targets (M=84.35, SE=2.87, 95% CI [78.70, 90.01]). There was no significant main effect found for participant group F(2,180)=0.27, p>0.05.

A B

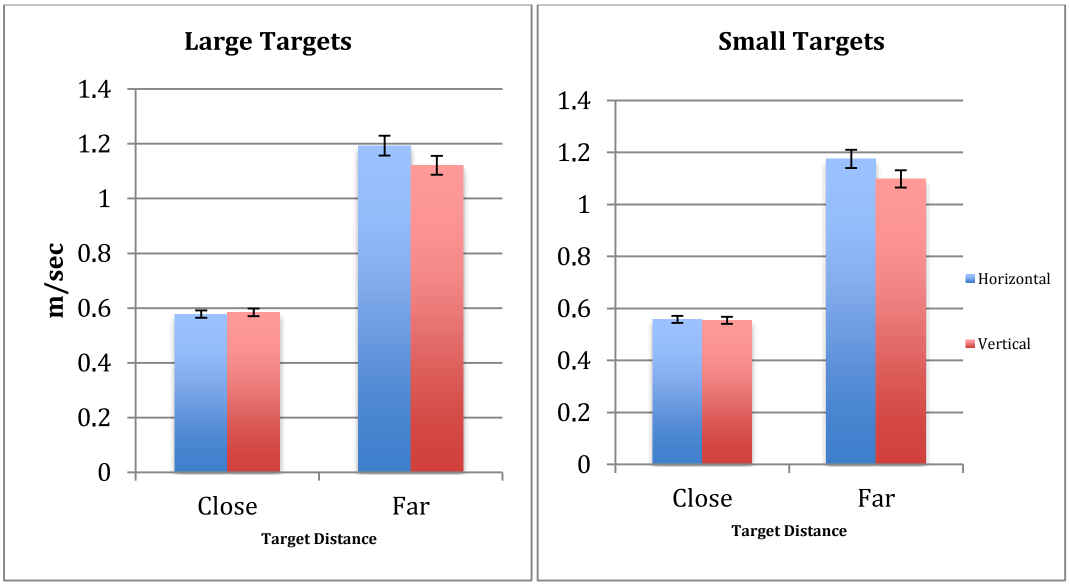

Figure 3: Peak Velocity Values shown for both horizontal and vertical orientations when the targets were close and far when the Target Width was large (A) and small (B) in both horizontal and vertical conditions.

Percentage Acceleration

There was significant interaction between participant Group and target distance $F(2,180)=3.85$, $p<0.05$. Post hoc tests showed that both normal weight and overweight spent significantly greater percentage of time accelerating in the conditions when the targets were further away (M=43.50%, SE=.57, 95% CI [42.37, 44.63] and M=45.38% SE=.78 95% CI [43.84, 46.92]) compared to when they were close (M=42.20% SE=.66 95% CI [40.89, 43.50] and M=42.11% SE=.90, 95% CI [40.34, 43.88]). There was also a main effect found for width $F(1,180)=86.21$, $p<0.01$, with participants spending significantly great percentage of time accelerating when the target were large (M=44.26% SE=.59, 95% CI [43.09, 45.42]) compared to when the target was small (M=41.59% SE=.59, 95% CI [40.43, 42.76]). There was no significant interaction effect found between participant group and Orientation ($p=0.7$) however there was a trend for obese participants to spend less time in the acceleration phase while the tablet was in the vertical orientation (M=40.84% SE=1.40, 95% CI [38.10, 43.58] compared to when in the horizontal position (M=43.52% SE=1.75, 95% CI [40.06, 46.98]).

A B

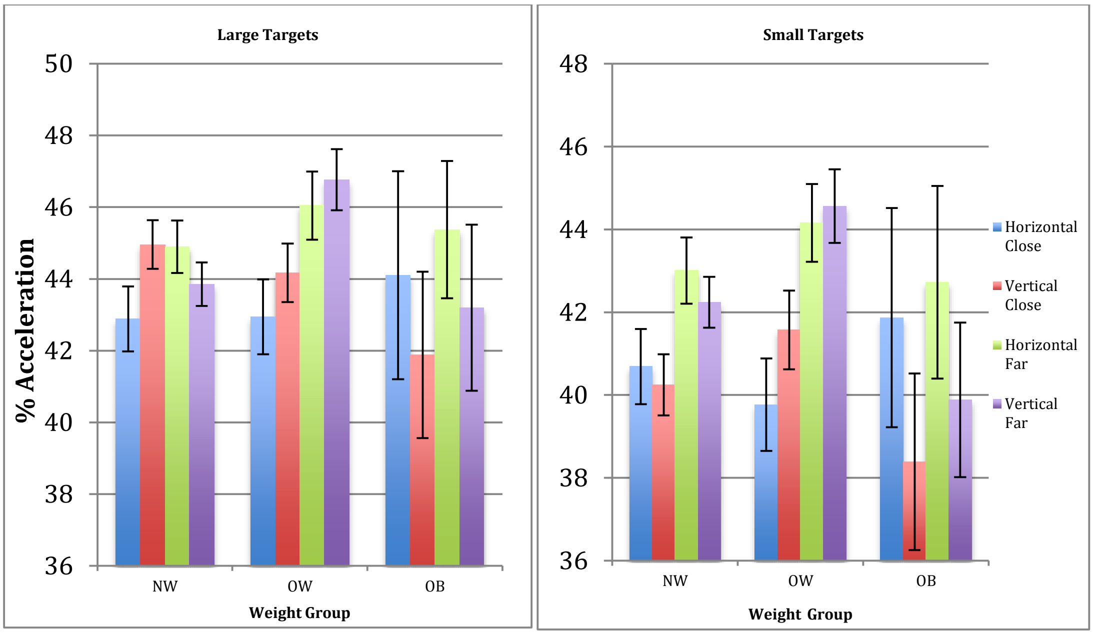

Figure 4: Percentage of time spent in Acceleration phase of movement shown for NW, OW and OB participant groups when the target width was Large (A) and Small (B) in both horizontal and vertical conditions.

Overshoot

There was a significant interaction effect found between BMI category and target distance F(2,180)=3.67, p<0.05. Post hoc analysis revealed obese (M=13.33, SE=1.92, 95%CI [9.54, 17.13]) participants to overshoot the target a significantly higher number of times compared to NW (M=6.45, SE=0.79, 95%CI [4.89, 8.00]) and OW (M=6.21, SE=1.07, 95%CI [4.01, 8.32]) peers when the target distance was further. There was a significant main effect found for target width (1,180)=178.02, p <0.01. Participants made more errors when the target was small (M=16.68, SE=1.21 95% CI [14.30, 19.06]) compared to when the targets were large (M=1.74, SE=0.34, 95%CI [1.07, 2.42]).

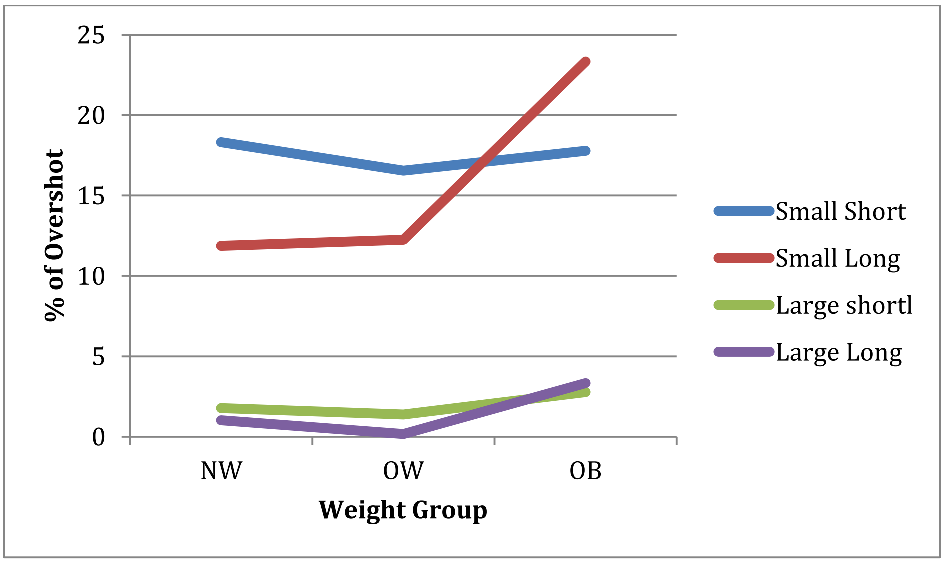

Figure 5: Percentage of trials which participants overshot target width shown for NW, OW and OB groups for all 4 conditions

Discussion

It is natural to perform goal directed aiming movements as quickly and as accurately as possible to make ensure efficient energy expenditure. It was found that increases in target distance and reduction in target width increased task difficulty as evident in results for Movement Time (Figure 1). The manipulation of target distance mainly affects the initial phase of the movement. When we increase target distance, we also see an increase in peak velocity (Figure 3). This results in increased duration of acceleration phase and as such an increase in overall movement time (MacKenzie et al. 1987; Heath et al. 1988).The duration of the deceleration phase also increased in proportion with the duration of the acceleration, which helps maintain a familiar bell shaped velocity profile. On the contrary, when the target size was reduced (increase in accuracy constraint), the velocity profile of the movement tends to become more asymmetrical (Carlton 1979; Carlton 1980; Meyer et al. 1988; Chua and Elliott 1993). The dissymmetry of the velocity profile is observed for high level accuracy constraint due to an increase of the deceleration phase (Carlton 1979; Meyer et al. 1988; Elliott et al. 1991; Chua and Elliott 1993). The duration of the acceleration phase remains almost unchanged regardless of the accuracy required. The increase in movement time stems from an increase in the deceleration phase and a lengthening of the period of movement closer to the target to allow time to take into account sensory information and allow adjustment of movement (Carlton 1979; Carson and Elliott 1993; Chua and Elliott 1993). Our study sought to modify tablet orientation as a means to manipulate task difficult. This resulted in 9.02%, 9.04% and 8.19%, increases in Movement Time for vertical Conditions for Large Close, Large Far and Small Close conditions respectively. The greatest increase was seen for Small Far condition, which had the highest index of difficulty, with a 16.28% increase in Movement Time for Vertical compared to Horizontal orientation. This finding was expected, as when in vertical tablet orientation, participants were required to hold their arm up rather than have it supported by the tablet during the horizontal condition. This requires the co contraction of the arm muscles for the vertical position. This requires greater muscle activation, which requires greater energy to maintain a similar degree of accuracy. The finding of a significant interaction effect between orientation and target width is a finding which has been seen in a number of other studies (Gribble 2003; Fernandez and Bootsma 2004; Loeches De La Fuente et al. 2014). When the accuracy constraints are high (small target) the added muscle co activation can be seen as a measure to help participants preserve movement accuracy by improving limb stability. This increased muscle activation is more energetically expensive and as such requires great time demands in order to implement thus resulting in increased movement time. This suggests that although more energetically more expensive, co activation during a manual aiming task could be used as a means to improve limb stability and increase movement accuracy (Gribble 2003). Finally in terms of errors, participants made more errors when the target width was small compared to when the target width was large (Figure 5). Globally, these results corroborate Fitt's Law and mirror the results classically found for a discrete Fitt's task paradigm carried out in a laboratory environment (Fitts and Peterson 1964; Elliott et al. 2001; Elliott et al. 2010). This finding point's to the robust nature of the Fitt's task given that this study was carried out on a larger scale and as part of a public exhibition rather than a laboratory setting traditionally used.

This study also demonstrated that obesity influences the speed and accuracy during a manual aiming task. Surprisingly, there was no significant difference found between groups for overall movement time regardless of tablet orientation, target distance or target width. This unexpected and interesting finding suggests that obese participants are able to maintain an equivalent level of performance in terms of movement time to their normal weighted peers. However, as we looked in greater depth at the movement kinematics, differences between groups emerged, demonstrating underlying differences in the control mechanisms in use. Obese individuals also demonstrated higher peak acceleration values when compared to NW and OW peers when their arm was supported in the horizontal orientations (Figure 2). However this difference disappeared, in a vertical condition, which suggests the increased postural/mechanical demands of supporting an arm resulted in altered movement control strategy. Secondly although non significant, there was a trend for obese individuals to demonstrate higher peak velocities than their peers for horizontal orientation but lower peak velocities when in the vertical orientation (Figure 3). This was particularly true when the target distance was further away (Large Far and Small Far). It is unexpected to find between group differences for peak velocity but not to observe differences in movement time. This suggests despite moving faster during the first phase of movement, obese participants still take the same amount of time to complete the task. Further analysis of movement also revealed that obese participants percentage of time in the acceleration didn't differ significantly between the most difficult conditions (Small Close and Small Far) while both NW and OW groups did. As the distance between targets increased between Small Close and Small Far, NW and OW participants spent significantly higher percentage of their MT in acceleration phase (Figure 4). However, obese participants percentage acceleration did not differ significantly. When the accuracy constraints are low, velocity profiles tend to have an equal distribution of time spent in acceleration and deceleration phases of movement (Fernandez and Bootsma 2004). As the need for precision increases, the velocity profiles become increasingly asymmetric with increased time being spent in the deceleration phase to preserve accuracy (Mottet and Bootsma 1999). Jeannerod (1984) attributed this slowing down to on-line sensorimotor integration during the movement's final phase while Carlton (1980) suggested that this slowing down might be corrective in nature. As such, the speed–accuracy trade-off is generally viewed as the consequence of both MT and movement endpoint variance minimization (Meyer et al. 1988; Harris and Wolpert 1998). As such when accuracy constraints are high, movement speed needs to reduced in order to decrease variability and maintain the desired outcome (Harris and Wolpert 1998).

As we can separate participant's movements into two distinct phases: ballistic and corrective, it appears that obese participants behaviour in each of these phases differ from their normal weight and overweight peers. In the first phase, obese participants demonstrate greater peak acceleration and achieve peak acceleration earlier in their movement and a trend for higher peak velocities. This finding in conjunction with the results for movement time suggests that OB demonstrate greater impulsivity in the initial ballistic phase of movement. A parallel can be found in studies examining response inhibition in obese individuals. These studies found that obese individuals demonstrated a more impulsive nature and a poorer response inhibition mechanism compared to normal weighted peers. (Lokken et al. 2009; Hendrick et al. 2012; Reyes et al. 2015; Brockmeyer et al. 2016). These higher peak accelerations in the ballistic phase of movement results in greater variance and therefore extended deceleration phases to make the required adjustments to maintain accuracy thus maintaining the same overall movement time. When in the vertical orientation, OB participants spent a lower percentage of time in the acceleration phase and more time in the corrective phase when their arm was unsupported, particularly when the target was smaller or further away. This could be a result of obese participants utilizing a slightly more conservative approach on conditions where they feel at risk of making errors. The presence of between group differences for number of errors is another interesting finding. Its normal to undershoot targets initially to avoid costly time/energy overshoot errors (Burkitt et al. 2015). We found that OB participants demonstrated significantly greater instances of error compared to their NW and OW peers particularly for the most difficult conditions (Figure 5). This can be seen as difficulty in the fine control of movement and specifically in the corrective phase of movement. This phase, which deals with the refinement and adjustment of movement, is an essential component of fine motor skill. These results seem to suggest that obese participants have difficulty in the utilisation of online feedback during movement. This requires them to spend a greater amount of time applying corrective adjustments at the end of their movements. Therefore the lack of movement time differences is as a result of a balancing between faster initial movements and greater time spent adjusting at the end of movements. This in essence means the initial movement time gains earned as a result of greater peak acceleration and peak velocities are required to offset costly overshoots and corrective measures at the end of the movement. A study by Heath, Hodges, Chua and Elliot (1998) found that participants initial ballistic movements tended to be determined prior to movement initiation and free from online adjustment. It seems that OB participants demonstrated a greater ballistic phase of movement that results in higher movement variability that requires greater adjustment in the second phase of movement and the associated increase in time decelerating. When taken altogether, these differences in movement kinematics demonstrate obese participants operating slightly difference motor control strategies dependent on the task constraints such as target distance, target width and orientation of tablet. This can effectively result in less efficient movement and potentially leading to more energy expenditure. Overall, obese participants seem to demonstrate a more varied array of movement characteristics compared to their normal weigh and overweight peers for when in the tablet was in a vertical orientation. This perhaps suggests the presence of thresholds where added postural demands of supporting ones arm in a vertical orientation interfere with movement control on goal directed aiming tasks. The lack of uniform group differences between obese and normal weight individuals can perhaps be seen as contrary to the traditional standpoint that excess mass acts as a mechanical constraint. These findings suggest that obese individuals are capable of altering their motor behaviour in order to preserve motor outcomes which acutely sacrificing speed or accuracy. Similar results have been seen in Parkinson's disease with patients found to be able to move at the same speed as controls but occurred with the expense of accuracy, with spread of movement end points (Phillips et al. 1994; Rand et al.

2000). Sanes (1985) suggested that Parkinson's patients couldn't process the same amounts of information per unit time as control participants.

The ability to coordinate movement while preserving speed and accuracy underpins all goal-directed aiming tasks. The successful completion of many activities of daily living such as picking up items, brushing ones teeth or buttoning a shirt require rely on this ability. As such, difficulties in the preservation of the speed and accuracy balance effect the interaction between individuals and the environment around them. Individuals who suffer from difficulties in coordination such as Developmental Coordination Disorder (DCD) or Dyspraxia frequently report problems in the successful execution of activities of daily living and decreased quality of life. Interestingly, there are strong associations between individuals with DCD being overweight or obese (Cairney et al. 2005; Wagner et al. 2011; Hendrix et al. 2014; Zhu et al. 2014).This opens up the question to whether these motor control difficulties exist prior to becoming obese or whether becoming obese leads to motor control problems. The presence of group differences for obese participants in the quality of movement adds further evidence to the hypothesis that obese influences the sensory integration process (D'Hondt et al. 2011; Gaul et al. 2016). As participation in physical activity often relies on the ability to coordinate movements quickly and accurately albeit on a whole body level, problems in this process can result in difficulties participating in such activities. This study adds further weight to the argument for underlying perceptual motor difficulties in obese individuals. Further research is required to determine whether these problems emerge as a result of the physiological changes when one becomes obese or whether these difficulties exist prior and contribute to becoming obese as a result of a vicious cycle of inactivity.

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	Normal Weight	Overweight	Obese	Total
N	107 (58.5%)	58 (31.7%)	18 (9.8%)	183 (100%)
M/F	37/70	33/25	7/11	77/106
Age (yrs)	34.18 ± 14.09	38.97 ± 14.42	41.72 ±16.55	36.44 ± 14.63
Weight (kg)	63.34 ± 8.17	79.90 ± 10.20	100.73 ± 16.81	72.26 ± 15.60
Height (cm)	170.56 ± 8.52	172.36 ± 10.12	170.94 ± 9.84	171.17 ± 9.17
BMI (kg/m^2)	21.72 ±1.77	26.79 ± 1.36	34.34 ± 4.00	24.57 ± 4.44

Figure1

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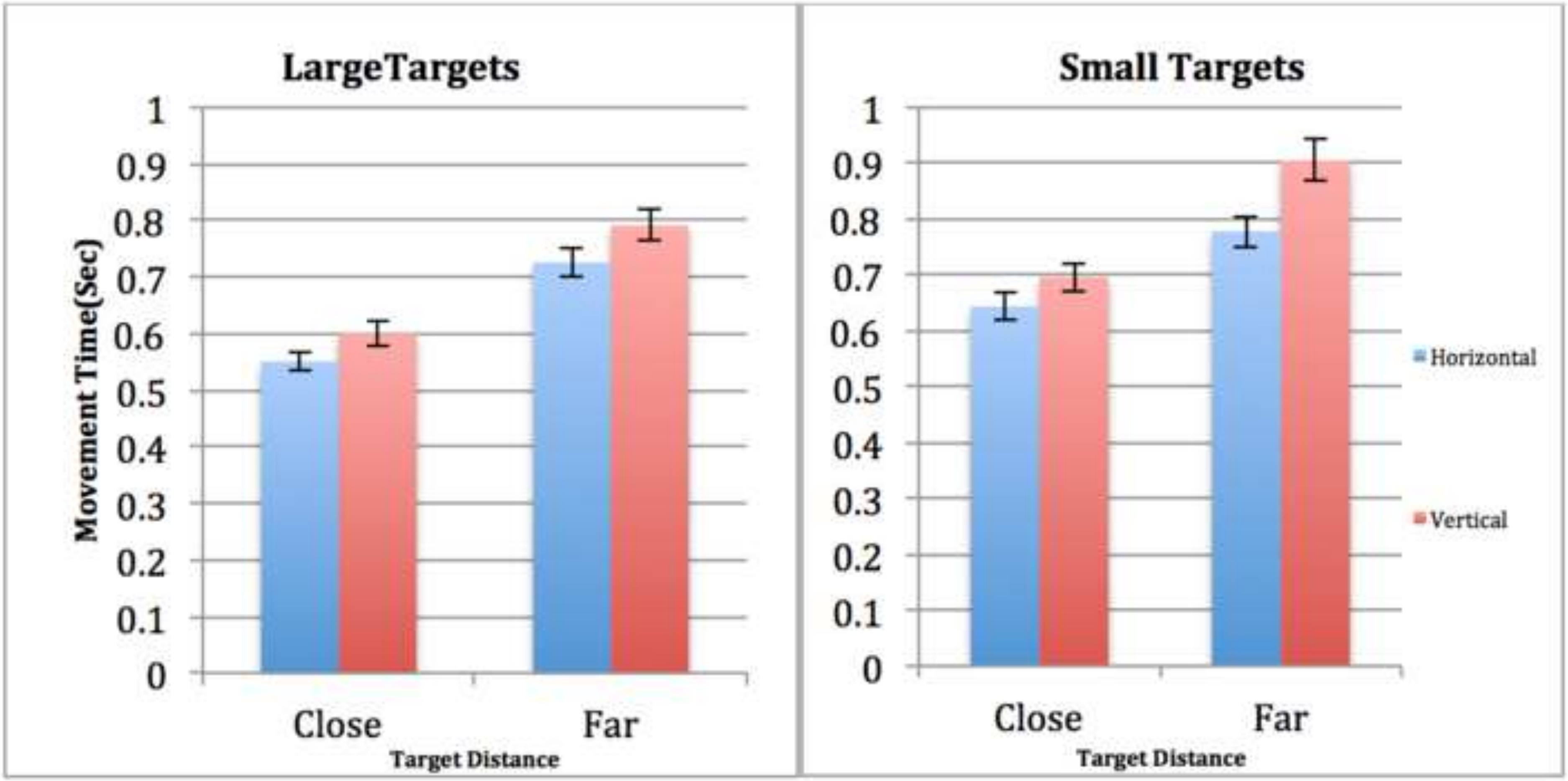

Figure2

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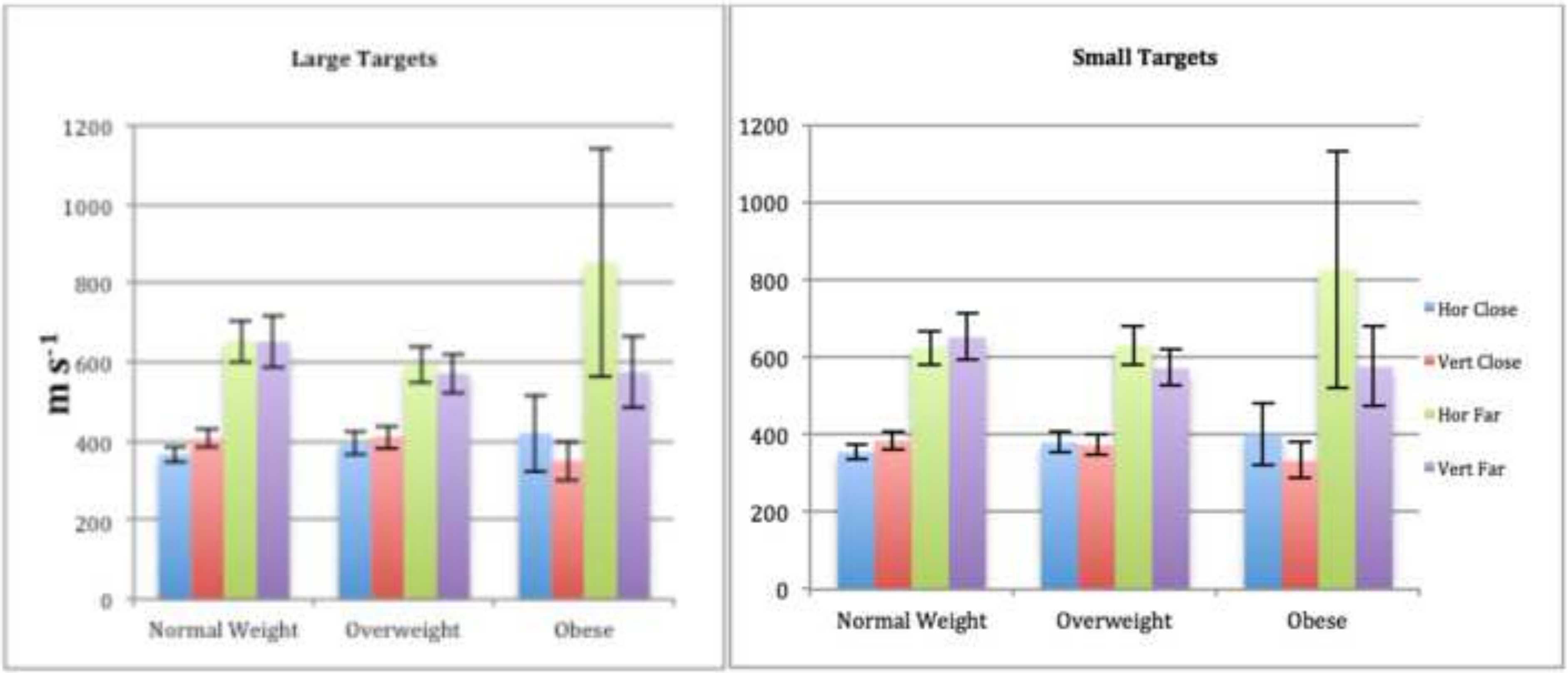

Figure3

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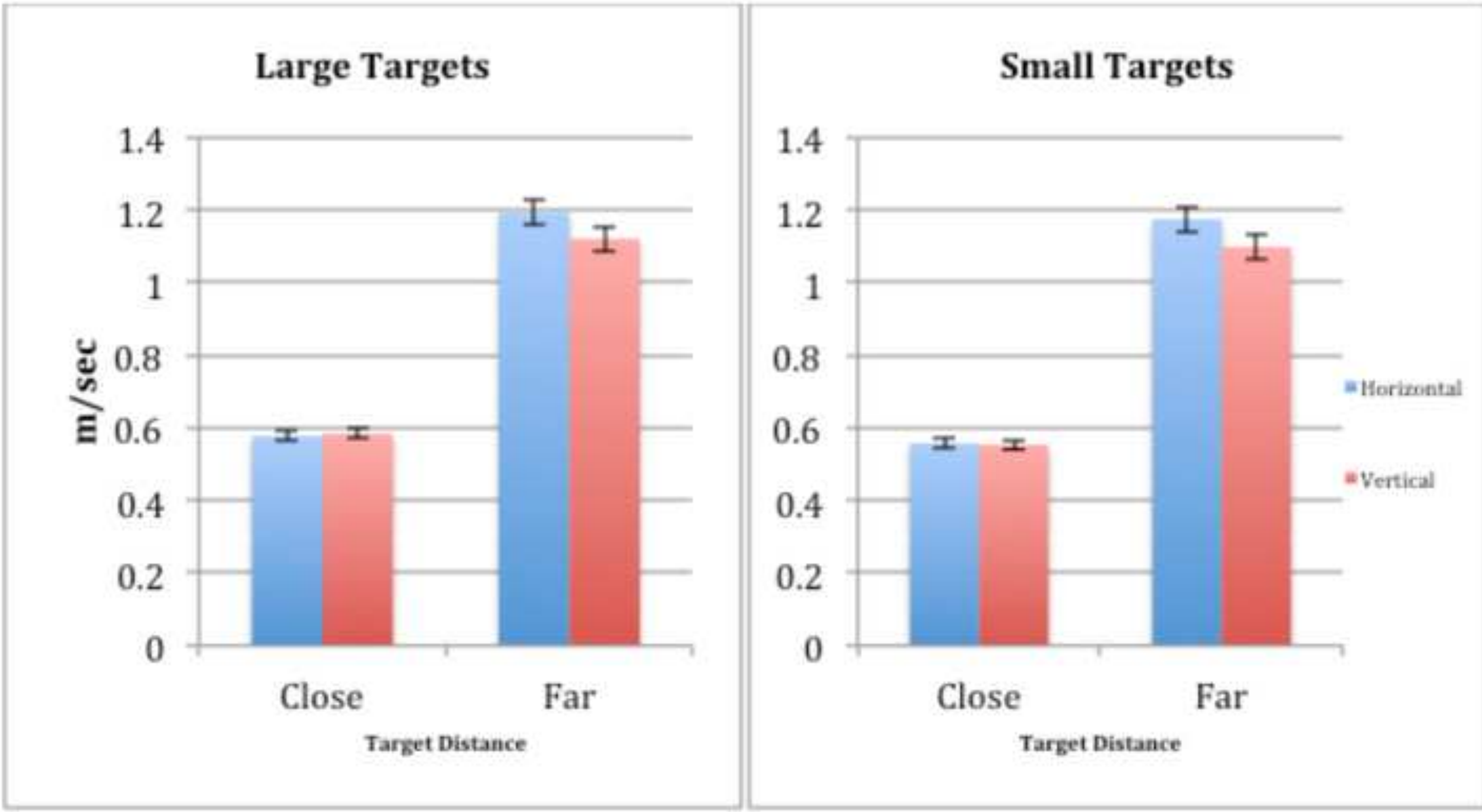

Figure4

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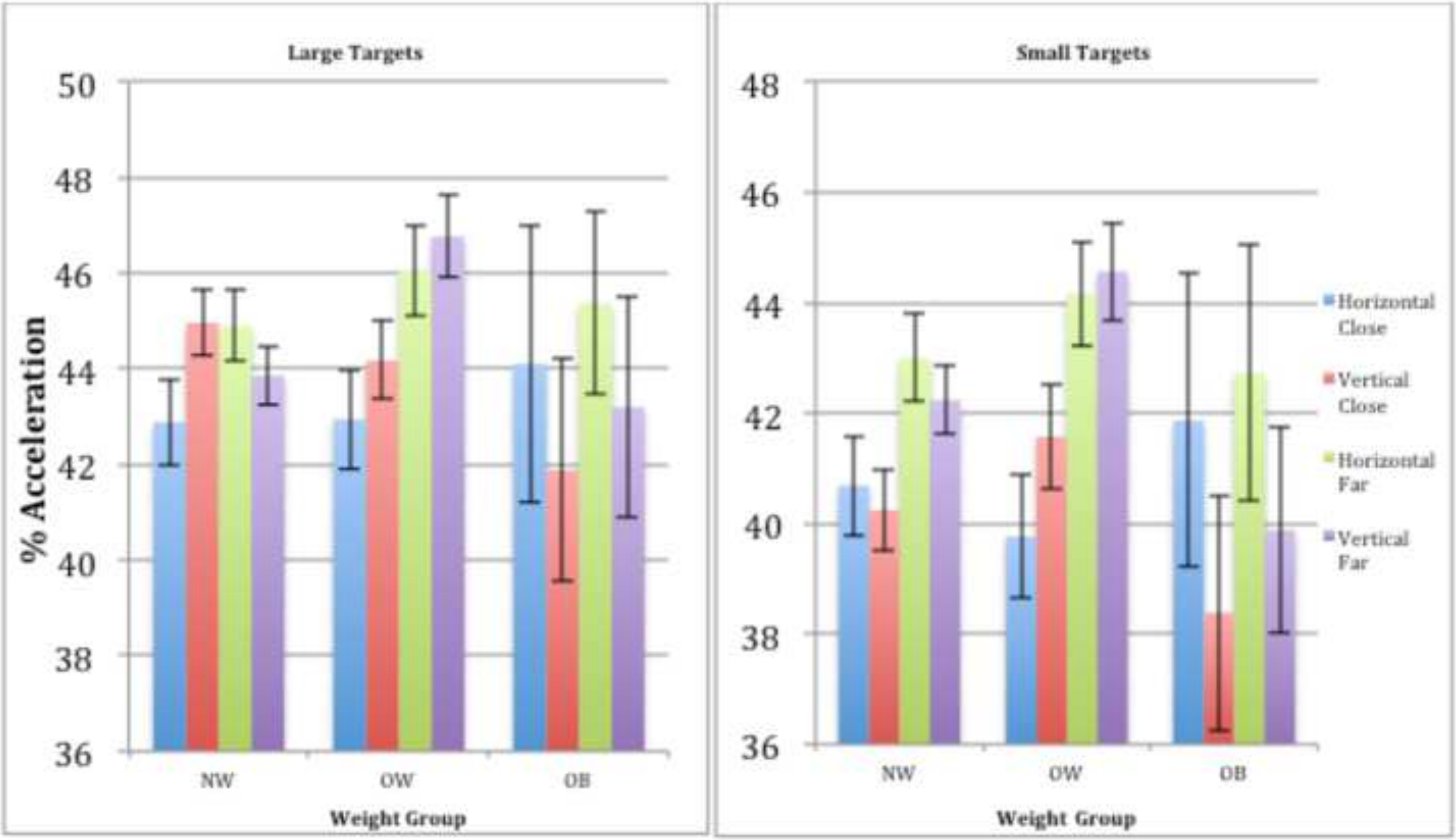

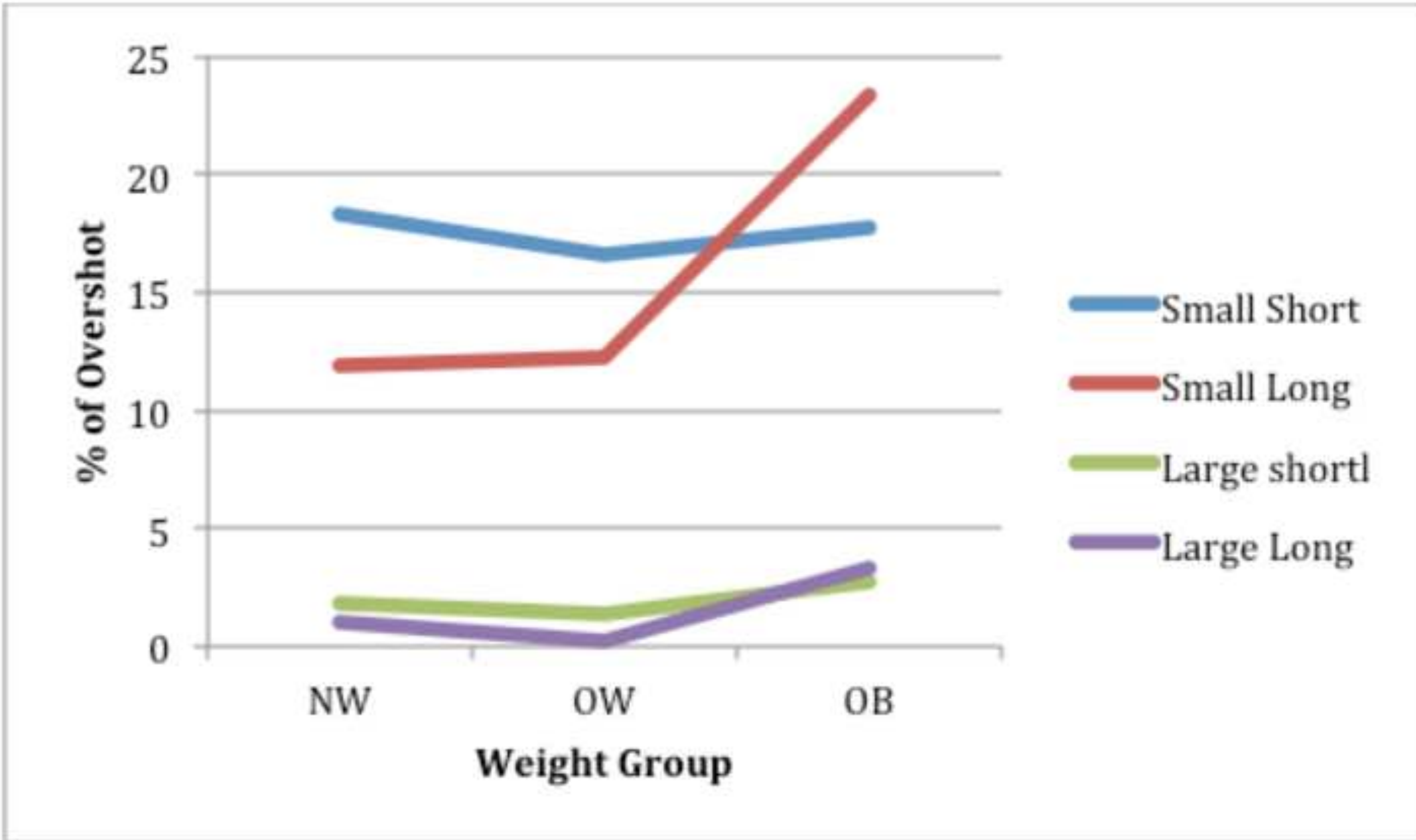
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