



HAL
open science

Role of Deltoid Muscle In Reducing Peak Forces In Forward Fall Simulation

Jean Mazeas, Maude Traullé, Mickael Acco, Nicolas Solignac, Florian Forelli

► **To cite this version:**

Jean Mazeas, Maude Traullé, Mickael Acco, Nicolas Solignac, Florian Forelli. Role of Deltoid Muscle In Reducing Peak Forces In Forward Fall Simulation. *International Journal of Orthopaedics Research*, 2020. hal-02933348

HAL Id: hal-02933348

<https://hal.science/hal-02933348v1>

Submitted on 8 Sep 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Role of Deltoid Muscle In Reducing Peak Forces In Forward Fall Simulation

Jean MAZEAS¹, Maude TRAULLE¹, Mickael ACCO¹, Nicolas SOLIGNAC² and Florian FORELLI^{1*}

¹OrthoLab, Movement analysis, Functional Exploration and Clinical Research

²Orthopaedic Surgeon, Clinic of Domont

*Corresponding author

Florian FORELLI, OrthoLab, Movement analysis, Functional Exploration and Clinical Research, 85 route de Domont, 95330 Domont, France.

Submitted: 25 Aug 2020; Accepted: 01 Sep 2020; Published: 08 Sep 2020

Abstract

Anticipation is one of the mechanisms to limit the risk of injury upon receipt of a fall by reducing impact forces. In this anticipation, the Deltoid muscle in particular plays an important role, but its activity has not been studied in this context. The purpose of this study is to investigate the anticipatory activity of the three Deltoid heads in a falling recovery movement, the hypotheses tested are that there is a correlation between the Deltoid anticipatory activity and the impact forces, and that bilateral differences between the studied parameters exist. 4 subjects performed a forward fall simulation, from which the impact forces and muscle activity of the Deltoid heads were measured with electromyography. This study shows that the anticipation activity of the anterior Deltoid is positively correlated to the impact forces, this correlation is not found on the anticipation of the other two heads, on the other hand there is an increased impact force associated with an early impact time on the left side, in accordance with the international literature. The results suggest that Deltoid plays a major role in falls anticipation and reception, and features an asymmetric motor pattern with a first contact of the non-dominant limb to improve the damping phase.

Keywords: Anticipation, Deltoid, Electromyography, Impact forces, Muscle activity

Introduction

In France, more than 15% of people over the age of 65 have fallen at least once in the past 6 months, and 25% are considered to be at risk of falling, and in an ever-growing population, the number of falls and its socio-economic impact is only increasing, notably linked to the numerous injuries associated with these falls, from simple contusion to major fractures of the pelvis, spine and skull [1-3].

Naturally, several protection mechanisms intervene to prevent and protect these areas from impact, allowing either the reequilibration of the center of gravity, or to better absorb the fall by using mainly the upper limbs. This second strategy, involving both the integration of sensory information and a set of motor patterns, is found more frequently in the elderly because rebalancing strategies are no longer sufficient to compensate for imbalances and maintain posture, mainly due to the decrease in muscle strength and reaction speed in this population [4,5]. However, this use of the arms to stop a fall is not significantly correlated with a reduction in the number of direct impacts of the head in the elderly, which shows a conservation of the protective reaction but a reduction in its

effectiveness [6].

The importance of impact forces results in more than a third of falls with impact of the hands in a bone or joint injury of the upper limb, localized mostly at the distal end of the radius by direct shock, but also injuries of the shoulder by transmission of the impact force through the arm [7].

The reception mechanism is conventionally divided into two phases: a first phase of preparation for the impact (anticipation) and a second phase of compensation of the impact (damping) [3,7]. The aim of anticipation is for the individual to be able to adjust the upper limb segments and to determine the muscular force necessary to absorb the impact enough to avoid a head shock, while retaining enough elastic capacity to reduce the maximum impact force in the upper limbs, directly responsible for the injuries reported. Anticipation is present both in fall simulations initiated by the subject and in falls triggered by an external element, but its effectiveness in reducing impact forces is greater in the first case.

In order to determine which factors come into play in the reduction of these impact forces, the muscular activity of several muscles, in particular the Triceps Brachialis, the Pectoralis Major and the muscles of the forearm has been studied in the literature, but very

little information exists on the activity of the Deltoid, which however plays an important role in this reception.

Some studies take into account the activity of the Deltoid in their measurements but do not analyze in detail its activity in the reception mechanisms.

The Deltoid however plays a crucial role in the fall reception. Its actions in anticipation can be divided into three categories, corresponding to one or more of its three heads. First of all, by its anterior and middle heads, the Deltoid allows the active placement of the humerus in flexion and abduction to present the hands in the direction of the fall. The middle portion also plays an important role in the stability and protection of the joint [8]: although retaining a mainly elevating component in the first degrees of abduction, the middle Deltoid has a coaptation component and therefore stabilizes the articulation [8]. Finally, the anterior and posterior heads allow by their co-contraction to stabilize the glenohumeral joint in the anteroposterior direction [9].

The purpose of this study is to analyze the electromyographic activity (EMG) of the three heads of the Deltoid when anticipating a forward fall. The main objective of this study is to determine if there is a correlation between the EMG activity of the Deltoid before impact and the maximum impact forces measured at the level of the upper limbs at reception. A second objective of this study is to assess the differences between the bilateral values measured in relation to the subject's handedness. This is a preliminary study, which aims to present a protocol making it possible to obtain coherent results which are relevant to the research question asked and to the international literature.

Materials and Methods

Study Population

The study was carried out on a population of healthy subjects selected from students in training institutes forming a unique group of asymptomatic subjects. The inclusion criteria for this study were: being between 18 and 30 years old, having a height between 150 and 180 cm and a weight between 50 and 70 kg, not having had a fracture or surgery on the upper limbs in the previous 2 years, not having a medical condition which could cause a disorder of neuro-motor coordination or balance, and not practicing sport leading to fall reception (martial arts etc...) [2,10].

Study exclusion criteria were also retained for this study, they correspond to a particular pain or fatigue on the day of the study, a partial or total inability to carry out the protocol, consumption of alcohol or psychotropic substances in the 24 hours before the test or a failure on more than 3 attempts during the test. Each participant was contacted individually, informed of the context of the study and provided their informed consent to participate.

A total of 4 participants underwent the protocol, under the supervision of the same assessor. The general characteristics of the participants are described in Table 1.

Table 1: Subjects general characteristics

Characteristic	Value
Subject Number	4
Mean Age (SD)	23 y (1,87)
Mean Height (SD)	163 cm (3,67)
Mean Weight (SD)	59 kg (4,53)
Handedness (L/R)	4/0
M = Male, F = Female, L = Left	
R = Right, SD = Standard Deviation	

Protocol

The electromyographic study was carried out using a MiniWave® system (Cometa, Bareggio, Italy) on the three heads of the Deltoid muscle on each side (6 wireless transmitters in total). Muscular activity is recorded over 1 sec before impact, at a frequency of 1000Hz. The average activity of each muscle bundle was recorded during this pre-impact phase.

The impact force was measured using two Accugait® platforms (AMTI, Watertown, United States), and all of the data was recorded and synchronized using Vicon Nexus® software (Version 2.5, Vicon Motion System, Oxford, England). The maximum impact force value was recorded for the analysis of the measurements, as well as the time mark corresponding to the first contact between the hands and the platform.

Before taking the measurement, the participants perform a warm-up consisting of 2 sets of 10 shoulder circumductions and then a series of 5 submaximal contractions for each beam.

The electrodes are placed after heating to avoid detachment, it is performed according to SENIAM standards to measure the muscular activity of the anterior, middle and posterior deltoid. Three isometric voluntary maximum contraction tests (MVIC) are carried out, the contraction is maintained for 5 sec with 30 sec of rest between each, alternating from the side. The maximum EMG value after treatment is used to normalize the set of EMG data for each subject, which will be expressed as a percentage of MVIC.

Before performing the test, oral explanations were given to participants, as well as a demonstration of the movement performed by the assessor. The subject settles down on his knee, hips straight, facing the platforms placed 50 cm forward. The choice of the position of the arms is left free to the participants for the rest of the measurements, it is specified that they must keep their back as straight as possible during the descent phase and contact the platforms with the palm of the hands first, to avoid a shift of the time marks due to an impact of the fingers before the palm [10].

This fall simulation protocol corresponds to an earlier fall with symmetrical reception on both hands. The subject is warned by an audible signal that the test begins, he leans forward and begins the descent phase, the goal is to place each hand in the middle of each corresponding platform. If the objective is reached and the subject's head has not come into contact with the platforms, the test is validated and the measurements of the force, electromyographic and kinematic platforms are recorded. A total

of 5 tests are carried out with 1 minute of rest between each test, during the rest phase the subject returns to position and prepares for the next test [3,6,10].

The EMG data collected are processed with a moving average over 100 values after centering and rectification of the signal, then normalized from the value of MVIC for each muscle and each subject. For the statistical analysis the EMG values at impact time as well as the average values on the pre-impact phase are used.

Statistical Analysis

Statistical analysis of the data was carried out using R® software (R Development Core Team 2011, Bell Laboratories, Murray Hill, United States) after extraction on Excel® spreadsheet. For this analysis, the significance threshold was defined such that $\alpha = 0.05$, therefore if p-value < 0.05 the test is considered to be statistically significant. To assess the correlations between EMG activity and impact forces, a Pearson correlation test was used. To assess the bilateral differences between the measured data, successive Wilcoxon tests were performed for each variable.

Results

The maximum activity of the anterior Deltoid, measured at the time of impact, was 36.87% MVIC ($\pm 13.55\%$). For the middle and posterior Deltoids, the activities were respectively 18.14% ($\pm 5.37\%$) and 14.06% ($\pm 0.91\%$) of the MVIC. As for impact forces, the average value measured was 531.42 N (± 61.7 N).

A significant correlation was found between the activity of the anterior Deltoid and the impact forces, with a correlation coefficient of 44.38% (p-value = 0.004). For the middle and posterior Deltoids the correlation tests performed, showed on Table 2 did not show significant results, the overall trend appeared to show no correlation, with respective coefficients of 11.81% and 14.59%.

Table 2: Correlations between Maximal Impact Forces and Deltoid muscle Activity

Correlation tested	P Value	Correlation coefficient
Impact Force - EMG DA	0,00412	0,4438
Impact Force - EMG DM	0,468	0,1181
Impact Force - EMG DP	0,3689	0,1459
EMG = Mean Muscle Activity, DA = Anterior Deltoid		
DM = Middle Deltoid, DP = Posterior Deltoid		

Bilateral differences in results were also measured, the values of the statistical tests are reported in Table 3. A significant difference in the activity of the posterior deltoid is found, with an average increase of 27.58% in this activity on the right side relative to the left side (p-value = 0.02831). An increase in the activity of the anterior Deltoid was also found on the left side compared to the right side (+ 16.36%) but without statistical significance. These results indicate an increase in the activity of the left anterior deltoid and the right posterior Deltoid.

Table 3: Difference between left and right values

Parameter tested Left/Right	P Value
Maximal Impact Force	0,1135
Mean Anterior Deltoid Activity	0,,5117
Mean Middle Deltoid Activity	0,211
Mean Posterior Deltoid Activity	0,02831

For the impact forces, an increase in the maximum measured forces is found in all the tests except 3, with an average increase of 66.35N. This value is also associated with hand contact on the left platform systematically earlier than the right side, with an average difference of 18ms.

Discussion

The positive correlation found between the activity of the anterior Deltoid and the impact forces seems at first glance to contradict the findings of Lattimer et al. in 2016, according to which the anticipatory muscular activity of the different muscles participating in the reception of a fall is negatively correlated with impact forces [2]. Several hypotheses can explain this difference. Firstly, this study relates to the Triceps Brachialis, the Biceps Brachialis, the Pectoralis Major and the anterior Deltoid, the authors indicate that the activity of the latter is significantly different from the other muscles studied.

These muscles presenting a role of shock absorbers of the fall, it is possible that the motor role of the anterior deltoid, allowing the placement of the arm in space, is the main role of this muscle during the anticipation phase. It is also possible that subjects with less strength available direct their strategy towards reception closer to reception with fully outstretched arms [2, 3,11]. Found in numerous studies on the falls of elderly people in particular, this strategy makes it possible to avoid an impact of the head by using less muscular force during the reception, on the other hand it induces by the lack of damping an increase in the forces of impact on the hand. To carry out this strategy, the subjects then increase the shoulder flexion necessary to place their hands at the level of the platforms, resulting in an increase in the activity of the anterior deltoid for these subjects [12].

With regard to the middle and posterior Deltoid, their activity does not seem correlated with the impact forces, however the increase in their activity during the anticipation phase seems to indicate a role of these muscles in the reception of the fall. The study by Billuart et al. in 2006 showed that the contraction of the middle Deltoid in the first degrees of shoulder abduction has a coaptation component of the glenohumeral joint [8]. On the other hand, the posterior Deltoid plays a role in glenohumeral stability in the sagittal plane, by its co-contraction with the anterior head [9]. It is therefore possible to say that the activity of these muscles in the pre-impact phase makes it possible to better stabilize the shoulder during reception.

Our second hypothesis was that there is a bilateral difference in the parameters studied in anticipation of a symmetrical fall. In this

study we were able to find bilateral differences in muscular activities as well as in impact forces recorded, associated with an asymmetry in the moment of impact of the hand on each of the platforms. In all of these values the left side is shown as the side of the first impact, with an increase in impact forces and in the activity of the anterior Deltoid and a decrease in the activity of the posterior Deltoid.

These results correspond to those found in two studies : the study by Troy et al. in 2007 and that of DeGoede et al. in 2002 also found an increase in the impact forces on the left side in their bilateral analysis, however in neither of these two studies assessed the correlation with the handedness of the subjects [13,14]. A third study by Lo et al. this time found an increase in the impact forces on the right side in one of the groups tested and on the left side for the second group tested, again without specifying the handedness of the subjects [15].

To explain this difference, two hypotheses are proposed by Troy et al. : firstly the difference in timing between the contact of the two hands seems in their study not to modify the total value of the maximum impact (two sides added) compared to the falls presenting a symmetrical diagram, on the other hand the orientation of this force is modified on the hand making the first contact, then approaching the axis of the radius in the asymmetrical diagram, thus limiting the shear stresses applied to the bone and therefore the risk of injury. As a second point, the authors indicate that the majority of real falls occur in an asymmetrical plane in a real context, it is therefore possible that the subjects prefer an asymmetrical motor response pattern even in the case where the fall is in a symmetrical plane [14].

To these hypotheses the current study seems to add that the subjects select a first contact systematically on their non-dominant member, thus leaving a delay after the contact of the hand to absorb the impact force, and so increasing the damping phase on this side. These results lead to the following hypothesis : this faster contact on the non-dominant side allows to move to the damping phase earlier than the dominant side, and therefore to have a longer time to recover from the fall may be necessary considering that the non-dominant side is weaker than the other, allowing greater reception efficiency. The counterpart of this early contact of the non-dominant hand is, however, an increase in the maximum impact constraints at this time at the hand level. The objective of these asymmetrical reception strategies would therefore be to avoid contact with the trunk or head during the fall by promoting damping on the weaker side, but not to reduce the maximum stresses applied to the arm during contact with the ground.

For muscle activity, the bilateral differences are not statistically significant, except for the posterior Deltoid which has a greater value on impact on the right side compared to the left side (p-value of 0.02831), we also find an increase in the activity of the left anterior Deltoid. This data can be correlated to the anticipated impact of the left side compared to the right side, thus supposing that the difference in impact time seems more related to the motor

pattern used rather than to a possible asymmetry of the study plan, this pattern then including a more important activity of the right posterior Deltoid and therefore a contact with the right platform delayed.

Limits and Perspectives

It is important to note that several elements in our study limit the conclusions which can be drawn from our results. The objective of this preliminary study remains to present initial results and a study protocol in order to better understand the mechanisms involved in the anticipation and reception of a fall. Firstly, this study is based on a fall simulation, a limit of this approach is the difficulty of reproducing a fall close to reality without presenting risks for the participants in the study, moreover the subject is warned and initiates himself the fall. However, the studies by Burkhart and DeGoede specify that if the fall takes place in a time greater than that necessary to anticipate it, as is the case in our study, the modification of the measured parameters is minor during the impact phase. between a fall triggered voluntarily and a fall suffered [3,7].

A second point limiting our observations is the age of the participants, selected from a young population, and it is therefore difficult to know if the results would be the same with older subjects or at risk of falling, the Merrill study in 2017 confirms in particular a modification of the motor patterns in the anticipation and reception of a fall according to the age of the subjects [16].

Finally, in our study all the subjects were right-handed, which limits the conclusions on a possible correlation between the laterality and the side with the greatest impact forces, the addition of a larger number of subjects including left-handers would validate the hypotheses set out in our study.

Conclusion

This study made it possible to determine that there is a positive correlation between the anticipation activity of the anterior beam and the impact forces when receiving a fall, which seems to depend on the differences in force between the subjects. On the other hand, the activity of the middle and posterior Deltoids does not seem to be correlated with the impact forces, but their activity is associated with stabilization of the shoulder joint. The bilateral differences found also make it possible to determine that the subjects achieve an asymmetrical fall pattern, presenting a contact in priority on the left arm, associated with an increase in the impact forces on this side and most likely linked to the laterality of the subjects. This information tends to show that the Deltoid plays a major role in the placement of the arm during the pre-impact phase, which determines the success of reception.

References

1. Carmen B Franse, Judith Ac Rietjens, Alex Burdorf, Amy van Grieken, Ida J Korfage, et al. (2017) A prospective study on the variation in falling and fall risk among community-dwelling older citizens in 12 European countries. *BMJ Open* 7: 015827.

2. Lauren J Lattimer, Joel L Lanovaz, Jonathan P Farthing, Stéphanie Madill, Soo Kim, et al. (2016) Upper limb and trunk muscle activation during an unexpected descent on the outstretched hands in young and older women. *J Electromyogr Kinesiol* 30: 231-237.
3. DeGoede KM, Ashton-Miller JA, Schultz AB (2003) Fall-related upper body injuries in the older adult : a review of the biomechanical issues. *J Biomech* 36: 1043-1053.
4. Klaas A Hartholt, Suzanne Polinder, Ed F van Beeck, Nathalie van der Velde, Esther M M van Lieshout, et al. (2012) End of the Spectacular Decrease in Fall-Related Mortality Rate: Men Are Catching Up. *Am J Public Health* 102: S207-S211.
5. Lo J, Ashton Miller JA (2008) Effect of Upper and Lower Extremity Control Strategies on Predicted Injury Risk During Simulated Forward Falls: A Study in Healthy Young Adults. *J Biomech Eng* 130: 041015.
6. Lauren J Lattimer, Joel L Lanovaz, Jonathan P Farthing, Stéphanie Madill, Soo Kim, et al. (2017) Female Age-Related Differences in Biomechanics and Muscle Activity During Descents on the Outstretched Arms. *J Aging Phys Act* 25: 474-481.
7. Burkhart TA, Andrews DM (2013) Kinematics, kinetics and muscle activation patterns of the upper extremity during simulated forward falls. *J Electromyogr Kinesiol* 23: 688-695.
8. Billuart F, Gagey O, Skalli W, D Mitton (2006) Biomechanics of the deltoideus. *Surg Radiol Anat* 28: 76-81.
9. Harrison A Latimer, James E Tibone, Marilyn M Pink, Karen J Mohr, Jacquelin Perry, et al. (1998) Shoulder reaction time and muscle firing patterns in response to an anterior translation force. *J Shoulder Elbow Surg* 7: 610-615.
10. Couzens G, Kerr G (2015) Anticipatory and Reactive Response to Falls: Muscle Synergy Activation of Forearm Muscles. *Hand Surg* 20: 343-351.
11. Merrill Z, Chambers AJ, Cham R (2017) Arm reactions in response to an unexpected slip-Impact of aging. *J Biomech* 58: 21-26.
12. P H Chou, Y L Chou, C J Lin, F C Su, S Z Lou, et al. (2001) Effect of elbow flexion on upper extremity impact forces during a fall. *Clin Biomech* 16: 888-894.
13. DeGoede KM, Ashton Miller JA (2002) Fall arrest strategy affects peak hand impact force in a forward fall. *J Biomech* 35: 843-848.
14. Troy KL, Grabiner MD (2007) Asymmetrical ground impact of the hands after a trip-induced fall: Experimental kinematics and kinetics. *Clin Biomech* 22: 1088-1095.
15. J Lo, G N McCabe, K M DeGoede, H Okuizumi, J A Ashton Miller, et al. (2003) On reducing hand impact force in forward falls: results of a brief intervention in young males. *Clin Biomech* 18: 730-736.
16. Merrill Z, Chambers AJ, Cham R (2017) Arm reactions in response to an unexpected slip-Impact of aging. *J Biomech* 58: 21-26.

Copyright: ©2020 Florian FORELLI, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.