The effects of position and size of drywall on the physical demands for installers

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Abstract The present study utilized an integrated biomechanical modeling approach that was previously developed by the researchers to investigate the effects of position and size of drywall on the physical demands for drywall installers. If the drywall sheets were stored vertically instead of flat, it reduced the required muscle contraction forces and joint reaction forces at the low back and shoulder approximately 8% on average during drywall installation. In particular, the L4/L5 disc compression forces and the absolute values of L4/L5 anterior-posterior shear forces decreased 6.1% and 8.5%, respectively, and at the shoulder during lifting the forces of rotator cuff muscles decreased 9.8%, and the coracohumeral ligament forces decreased 12.8%. The reaction forces at both the GH (glenohumeral) and SC (sternoclavicular) joints were reduced 7.2% and 3.6%, respectively. The larger size (e.g., 4x12 and 4x16) of drywall sheets increased the physical burden for the installers tremendously and could expose them to a higher risk of musculoskeletal injuries and disorders. In some simulations the average low back lateral shear forces increased to 1675 N and 2152 N, respectively. These forces are well above the 1000 N recommended for a single lift. These results indicated that it would be physically too difficult or even impossible for one person alone to lift bigger and heavier drywall sheets. Therefore, sound engineering (e.g., lifting tables) and/or administrative (e.g., two-person team work) solutions to handling oversized drywall sheets are strongly recommended.

INTRODUCTION

Construction workers who perform drywall installation are at a high risk of various musculoskeletal injuries and disorders, especially to the low back and shoulder areas (Chiou et al., 2000; Hsiao and Stanevich, 1996; Lemasters et al., 1998; Lipscomb et al., 1997, 2000). The manufacturers of drywall recommend that it be stored flat, in part because they have been found liable for not warning customers of the risk of injury from drywall falling over if stored vertically. This has resulted in drywall installers using a significant amount of awkward postures and enormous forces during lifting of the sheets.

In order to make drywall lifting easier, some contractors deliver the drywall to the site in a vertical position and then have it unloaded and stored vertically on a cart or directly on the floor against a wall. Nevertheless, the stability of drywall storage in a vertical position has caused great concerns. The *RockSteady® Clip* is a drywall stabilizing clip that virtually eliminates the risk of incidental or accidental tip-over of vertically stacked drywall (RockSteady LLC, 2009). It works by securing drywall sheets in a leaning position, keeping the stack from being pulled forward.

The sizes of drywall sheets are increasing due to industry demands. For decades, the standard size was 4x8, but now 4x12 is becoming standard and 4x16 is being used more frequently, especially on jobs where the workers are paid by the piece. This has unduly exacerbated the physical stress on the installers, and increased the needs for ergonomic solutions for drywall handling.

Previous biomechanical analyses of drywall installation examined the physical stress and postural stability during lifting of the drywall panels (Pan and Chiou, 1999; Pan et al., 2002/2003). The authors were aware of many practical limitations to conducting accurate, non-invasive and reasonably priced ergonomic assessments at the worksite due to the dynamic nature of construction activities. Therefore, more reliable and cost-effective ergonomic exposure assessment methods are warranted.

With the development and application of PATH (Posture, Activity, Tools, and Handling), an observational work sampling-based approach to direct observation (Buchholz et al., 1996), it has become practical to quantify the percent of time that construction workers are exposed to awkward postures, various tasks and activities, and manual handling (Buchholz et al., 2003; Forde and Buchholz, 2004; Fulmer et al., 2004; Paquet et al., 1999, 2001, 2005; Rosenberg et al., 2006). PATH has also been used in other industrial sectors that involve non-repetitive job activities including retail, agriculture, and healthcare industries (Earle-Richardson et al., 2005; Pan et al., 1999; Park et al., 2009).

The joint angle and load ranges that are represented by the PATH data are categorical rather than continuous. However, the Monte-Carlo simulation method, which is used to generate random numbers from a defined distribution, can be utilized to extract discrete values from the categorical PATH data for biomechanical analysis of the low back and shoulder (Tak et al., 2007). The Monte-Carlo method has also been successfully used both to capture the trunk muscle activity during torso bending (Mirka and Marras, 1993) and to simulate variability in muscle moment arms and physiological cross-sectional areas for prediction of shoulder muscle force (Chang et al., 2000; Hughes, 1997).

The researchers have previously explored a hybrid model integrating work sampling, computer simulation, and biomechanical modeling to conduct the ergonomic analysis of drywall installation (Yuan, 2006; Yuan et al., 2007). This modeling approach has been validated recently (Yuan, 2013) in a study funded by CPWR (Center for Construction Research and Training) Small Studies Program. The present study was designed to evaluate the impact of drywall position and size on the physical demands for drywall installers.

METHODS

Overview of methods

The integrated modeling approach started with the PATH methodology which provided the basic characterization of drywall installation work by quantifying the percent of time that the drywall installers were conducting different activities with different body segment (trunk, arm, and leg) postures. The relative frequencies of key activities, recorded over two hours, were used to construct eight-hour-workday activity series using Monte-Carlo simulation. The biomechanical model input variables, including anthropometric data, joint angles, external load force and position vectors, and internal muscle parameters, were then generated for the analyses of the low back and shoulder. Utilizing different optimization programs in MATLAB (The MathWorks, Natick, MA, USA), the three-dimensional static equilibrium equations were solved and the biomechanical model output variables of muscle contraction forces and joint reaction forces at the low back and shoulder were computed.

Seven main activities which represent a typical drywall installation task were examined in this study, including: 1. cut/measure; 2. lift; 3. carry; 4. hold/place; 5. screw; 6. in between; and 7. other. It was determined from the field observations that there were 12 possible work cycles, with 4 occurring during installation of a whole sheet and 8 denoting installation processes for a partial piece. The probability of each work cycle was calculated by multiplying the probability of every single activity during that cycle (Yuan, 2006). As studied by Pan and Chiou (1999), the drywall lifting method in which the worker used one hand to support the horizontal drywall sheet at its bottom and the other hand to grasp the sheet at its top produced the highest L4/L5 disc compression forces and therefore appeared to be the most stressful. It was assumed that the drywall installers in this study exclusively used such a lifting method as a demonstration of the worst case scenario. Activity 6 (in between) denoted exclusively loading/adjusting the screw guns and it always followed activity 5 (screw). Activity 7 (other) included climb/descend, communicate, mark/draw, and other miscellaneous job activities.

The drywall sheets studied in this project were Sheetrock® Brand Gypsum Panel from CGC Inc., with bulk density of 881 kg/m^3 (55 lb/ft^3). Summary statistics for subject weight, height, trunk widths and depths were acquired from Marras et al. (2001), because subject anthropometry was not obtained when the original PATH data were collected. The present study assumes subject height and weight follow a normal distribution because height and weight are generally known to be normally distributed (Roebuck et al., 1975). This assumption has been validated by Jung et al. (2009) using the 1988 US Army data (Gordon et al., 1988).

The relationships between subject trunk muscle parameters and anthropometric characteristics, such as subject height and weight, body mass index, and trunk width and depth at the planes of muscle origins and insertions, were determined from Marras et al. (2001). The regression equations with higher R squares were chosen in this study to represent those relationships. The weight percentages of different body segments of the whole body and the distance coefficients between the body segment center of mass and the proximal joint were calculated based on information from Drillis and Contini (1966) and Dempster (1955), respectively.

Application of the modeling approach

The model input values were changed when the drywall was stacked vertically instead of flat on the ground, or when the size of the drywall sheet increased. Based on the validation analysis (Yuan, 2013), it was assumed that the drywall installers used the same posture to handle bigger drywall sheets; yet, those sheets caused increases in the weight that was being handled as well as in the number of screws that were required to fasten the sheets. Furthermore, the drywall installers' hand location on the drywall sheets might have changed when the size increased. The impact on the low back and shoulder when the hands were placed approximately 1 foot right of the vertical middle line of the drywall sheets during activity 2 (lift) was examined.

When the drywall sheets were stacked vertically, the drywall installers were able to use more neutral trunk postures during activity 2 (lift). Activity 7 (other) referred to the assembling/disassembling of the *RockSteady® Clip* exclusively. Based on a video that was previously recorded on this particular activity, the drywall installers usually used the same screwdriver (DeWalt Heavy-Duty VSR Drywall Screwdriver – DW252, weighing 12 N) that was used for activity 5 (screw) to both fasten the clip to the drywall sheets and take it off. Thus, similarly to activity 5 (screw), both a horizontal reaction force along the Y-axis (directed forward) of the coordinate system for the low back model (Yuan, 2006) and a reaction torque about the Y-axis were added due to the manipulation of the screwdriver. Their values were assumed as

10 N and 7 N*m, respectively, according to the screwdriver's specifications. These data, along with the assumptions that have been validated from Task 1, were used as bases for generating the new model input values.

Percent Decrease/Increase of the model output values, primarily the required muscle contraction forces and joint reaction forces at the low back and shoulder under different case scenarios including changes of drywall storage position and size, were calculated to demonstrate the impact of drywall position and size on the physical demands for drywall installers. The general equation for calculating Percent Decrease/Increase is

$$\text{Percent Decrease/Increase} = \left|\frac{V_{pre} - V_{post}}{V_{pre}}\right| * 100\% \quad (1)$$

Where,
V_{pre} = Value of model output values before change
V_{post} = Value of model output values after change

Student t-tests ($p < 0.05$) were used to compare the means (e.g. vertical storage position vs. flat, and installation of 4X12 drywall sheets vs. 4X8) of muscle forces and joint reaction forces at the low back for an average subject working on a typical 8-hour workday. Since the differences were all statistically significant, we only presented the results of Percent Decrease/Increase in this paper.

Because of the limitations of the shoulder model, the impact of drywall storage position and size on the shoulder was examined based on the comparisons of model output values for activity 2 (lift) for an average subject working on 10 hypothetical work cycles of a typical 8-hour workday.

RESULTS

Impact of drywall storage position

For the low back model, the absolute values of trunk flexion, lateral bending, and twisting angles for an average subject working on a typical 8-hour workday decreased 3.8%, 15.4%, and 8.6%, respectively, when the drywall sheets were stored vertically instead of flat. The MMCI (Maximum Muscle Contraction Intensity) and the forces of two major pairs of trunk muscles (Erector Spinae and Latissimus Dorsi) also decreased an average of 8.2%. The absolute values of L4/L5 lateral shear forces did not change; however, the L4/L5 disc compression forces and the absolute values of L4/L5 anterior-posterior shear forces decreased 6.1% and 8.5%, respectively. These reductions were even more evident when only activity 2 (lift) was compared.

For the shoulder model, the absolute values of trunk flexion, lateral bending, and twisting angles, as well as the shoulder flexion angles for an average subject working on 10 hypothetical work cycles of a typical 8-hour workday decreased 4.0%, 7.0%, 19.2%, and 9.2%, respectively, when the drywall sheets were stored vertically instead of flat. For activity 2 (lift), the forces of rotator cuff muscles (consisting of supraspinatus, infraspinatus, subscapularis, and teres minor) decreased 9.8%, and the coracohumeral ligament forces decreased 12.8%. The reaction forces at both the GH (glenohumeral) and SC (sternoclavicular) joints reduced 7.2% and 3.6%, respectively.

These results indicated that the physical loads at the low back and shoulder during drywall installation, especially during drywall lifting, were reduced if the drywall sheets were stored vertically.

Impact of drywall size

If the size of drywall sheets was increased from 4x8 to 4x12, the MMCI and the forces of two major pairs of trunk muscles would increase an average of 12.3% (Table 1). This would also result in an average increase of 11.6% (Table 2) for the absolute values of the L4/L5 joint reaction forces (disc compression, lateral shear, and anterior-posterior shear, respectively). If the hands were placed approximately 1 foot right of the vertical middle line of the drywall sheets, the average increases of the MMCI and required muscle contraction forces, and joint reaction forces were even higher at 19.4% (Table 1) and 26.1% (Table 2), respectively. However, these increases were not symmetrical as the right lumbar erector spinae muscle forces and L4/L5 anterior-posterior shear forces showed much smaller increases compared to others. All of the increases were even more evident when only activity 2 (lift) was compared.

Table 1 Percent increases of MMCI and two major pairs of trunk muscle forces for installation of 4x12 and 4x16 drywall sheets

Percent Increase	MMCI	LEL	LER	LDL	LDR	Average
4x12 VS 4x8	11.6%	12.1%	12.2%	13.3%	12.3%	12.3%
4x12 Right VS 4x8	20.3%	21.5%	8.8%	27.4%	18.8%	19.4%
4x16 VS 4x8	25.4%	26.9%	27.2%	31.1%	30.2%	28.2%
4x16 Right VS 4x8	37.4%	39.9%	21.8%	50.4%	40.6%	38.0%

Note: MMCI – Maximum Muscle Contraction Intensity; LEL – Left Lumbar Erector Spinae; LER – Right Lumbar Erector Spinae; LDL – Left Latissimus Dorsi; LDR – Right Latissimus Dorsi.

Table 2 Percent increases of the L4/L5 joint reaction forces for installation of 4x12 and 4x16 drywall sheets

Percent Increase	COMP	ABS(LS)	ABS(APS)	Average
4x12 VS 4x8	10.8%	10.6%	13.5%	11.6%
4x12 Right VS 4x8	19.1%	52.2%	7.0%	26.1%
4x16 VS 4x8	23.7%	15.1%	33.0%	23.9%
4x16 Right VS 4x8	34.8%	74.7%	24.9%	44.8%

Note: COMP – Disc compression force; ABS(LS) – Absolute value of lateral shear force; ABS(APS) – Absolute value of anterior-posterior shear force.

The shoulder model results yielded increases in muscle (rotator cuff muscle, 5.0%, and coracohumeral ligament, 59.9%) forces and joint (GH, 38.1%, and SC, 37.5%) reaction forces as well, when 4x12 drywall sheets were installed.

If the size of drywall sheets was increased from 4x8 to 4x16, the percent increases on average for the MMCI and required muscle contraction forces, and joint reaction forces were 28.2% (Table 1) and 23.9% (Table 2), respectively. When the subject lifted the sheets from 1 foot right of the vertical middle line, it resulted in even more percent increases. Surprisingly, the absolute values of the L4/L5 lateral shear forces went up by 74.7%, and when only activity 2 (lift) was compared, such forces were higher than three times of the ones when 4x8 sheets were lifted.

Similar patterns occurred to the shoulder model, where much higher muscle contraction forces and joint reaction forces were required to lift the 4x16 sheets (Table 3). In particular, the rotator cuff muscle forces almost tripled, which indicated much different increases when compared to the installation of 4x12 sheets.

Table 3 Percent increases of rotator cuff (RC) muscle and coracohumeral (COL) ligament forces, as well as glenohumeral (FGH) and sternoclavicular (FSC) joint reaction forces for lifting of 4x16 and 4x12 drywall sheets

Percent Increase	RC	COL	FGH	FSC
4x12 VS 4x8	5.0%	59.9%	38.1%	37.5%
4x16 VS 4x8	192.8%	100.6%	94.9%	85.7%

DISCUSSIONS

The present study utilized an integrated biomechanical modeling approach that was previously developed by the researchers to investigate the effects of position and size of drywall on the physical demands for drywall installers. The required muscle contraction forces and joint reaction forces at the low back and shoulder reduced approximately 8% (with a range of 3.6% ~ 12.8%) if the drywall sheets were stored vertically and spiked if the size of drywall sheets increased. These changes were even more notable for the exclusive comparison of the activity 2 (lift), which could be used as guidance to help ASTM (American Society for Testing and Materials) make recommendations about drywall. Specifically, those 4x12 and 4x16 sheets increase the physical burden for drywall installers tremendously and could expose them to a higher risk of musculoskeletal injuries and disorders.

To ensure more accurate comparisons of model output values due to the changes of drywall storage position and size, the present study used previously collected and/or available data including observational, anthropometric, and muscular ones as bases for computer simulation. Only minimum necessary changes were made to the model input values for the evaluations of vertical storage position and bigger sizes of sheets, respectively; and it was assumed that the drywall installers would have to maintain the same productivity for a typical 8-hour workday under different circumstances.

Nevertheless, the PATH data especially those postural ones could have changed significantly when the drywall sheets were stored vertically or even when the size of the sheets increased. Similarly, the changes of PATH activity data with the use of the *RockSteady® Clip* could also warrant more PATH data collection. On the other hand, the present study assumed that the clip allowed the storage of drywall in a safe and secure manner and did not produce negative impact on the work efficiency and productivity; yet, it would be still useful to visit a site to see how the clip is used in practice.

Both the low back and shoulder model output values including the MMCI, the required muscle contraction forces, and joint reaction forces became much higher, especially for lifting of 4x12 or 4x16 sheets. Some of the results are beyond the normal ranges that have been published by previous studies. For example, the average erector spinae forces for lifting a 4x16 sheet were estimated to be approximately 7400 N, which is bigger than the normal range (2200 N ~ 5500 N) of the strength capability in a healthy population (Farfan, 1973). If the installer was to lift the 4X12 and 4X16 sheets from 1 foot right of the vertical middle line, the average L4/L5 lateral shear forces would increase to 1675 N and 2152 N, respectively, which are well above the 1000 N recommended for a single lift (McGill, 1997). These results indicated that it would be physically too difficult or even impossible for one person alone to lift bigger and heavier drywall sheets. Therefore, sound engineering (e.g., lifting tables) and/or administrative (e.g., two-person team work) solutions to handling oversized drywall sheets are strongly needed.

CONCLUSION

The application of computer-aided simulation to convert observational work sampling data into continuous variables as inputs for biomechanical modeling permitted a feasible estimation of the physical loads on the low back and shoulder during drywall installation. When the modeling approach was used to study the impact of the drywall storage position and size on the physical demands for drywall installers, it was determined that the required muscle contraction forces and joint reaction forces at the low back and shoulder decreased if the drywall sheets were stored vertically instead of flat. On the other hand, the larger size (e.g., 4x12 and 4x16) of drywall sheets increased the physical burden for drywall installers greatly and could expose them to a higher risk of musculoskeletal injuries and disorders.

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REFERENCES

Buchholz B, Paquet VL, Punnett L, Lee D, Moir, S. PATH: A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. Applied Ergonomics 1996; 27:3, 177-87.

Buchholz B, Paquet VL, Wellman, H, Forde, M. Quantification of ergonomic hazards for ironworkers performing concrete reinforcement tasks during heavy highway construction. American Industrial Hygiene Association Journal 2003; 64:2, 243-50.

Chang YW, Hughes RE, Su FC, Itoi E, An KN. Prediction of muscle force involved in shoulder internal rotation. Journal of Shoulder and Elbow Surgery 2000; 9:3, 188-95.

Chiou SS, Pan CS, Keane P. Traumatic injury among drywall installers, 1992 to 1995. Journal of Occupational and Environmental Medicine 2000; 42:11, 1101-8.

ConstructionKnowledge.net. http://www.constructionknowledge.net/blog/?tag=rock-steady-drywall-clip (last accessed on March 1, 2014)

Dempster WT. Space requirements of the seated operator, WADC-TR-55-159, Aerospace Medical Research Laboratories, Dayton, Ohio; 1955.

Drillis R, Contini R. Body segment parameters, BP174-945, Tech. Rep. No. 1166.03, School of Engineering and Science, New York University, New York; 1966.

Earle-Richardson G, Jenkins P, Fulmer S, Mason C, Burdick P, May J. An ergonomic intervention to reduce back strain among apple harvest workers in New York State. Applied Ergonomics 2005; 36:3, 327-34.

Farfan H. Mechanical disorders of the low back. Philadelphia: Lea and Febiger; 1973.

Forde M, Buchholz, B. Task content and physical ergonomic risk factors in construction ironwork. International Journal of Industrial Ergonomics 2004; 34:4, 319-33.

Fulmer S, Agyem-Bediako, S, Buchholz, B. Ergonomics: the impact of an intervention for lifting hazards during installation of overhead electrical conduit. Journal of Occupational and Environmental Hygiene 2004; 1, D80-4.

Gordon CC, Bradtmiller B, Churchill Y, Clauser CE, McConville JT, Tebbetts IO, Walker RA. 1988 Anthropometric Survey of U.S. Army [data file]. Available from National Technical Information Service Website, http://www.ntis.gov.

Hsiao H, Stanevich RL. Injuries and ergonomic applications in construction. In: Bhattacharya A and McGlothlin JD, editors. Occupational Ergonomics, Theory and Applications. New York: Marcel Dekker, Inc; 1996. p. 545-68.

Hughes RE, An KN. Monte Carlo simulation of a planar shoulder model. Medical & Biological Engineering & Computing 1997; 35, 544-8.

Jung K, Kwon O, You H. Development of a digital human model generation method for ergonomic design in virtual environment. International Journal of Industrial Ergonomics 2009; 39:5, 744-8.

Lemasters GK, Atterbury MR, Booth-Jones AD, Bhattacharya A, Ollila-Glenn N, Forrester C, et al. Prevalence of work related musculoskeletal disorders in active union carpenters. Occupational and Environmental Medicine 1998; 55, 421-27.

Lipscomb HJ, Dement JM, Loomis DP, Silverstein B, Kalat, J. Surveillance of work-related musculoskeletal injuries among union carpenters. American Journal of Industrial Medicine 1997; 32, 629-40.

Lipscomb HJ, Dement JM, Gaal JS, Cameron W, McDougall V. Work-related injuries in drywall installation. Applied Occupational and Environmental Hygiene 2000; 15:10, 794-802.

Marras WS, Jorgensen MJ, Granata KP, Wiand B. Female and male trunk geometry: size and prediction of the spine loading trunk muscles derived from MRI. Clinical Biomechanics 2001; 16, 38-46.

McGill, SM. The biomechanics of low back injury: implications on current practice in industry and the clinic. Journal of Biomechanics 1997; 30:5, 465-75.

Mirka GA, Marras WS. A stochastic model of trunk muscle coactivation during trunk bending. Spine 1993; 18:11, 1396-409.

Pan CS, Chiou SS. Analysis of biomechanical stresses during drywall lifting. International Journal of Industrial Ergonomics 1999; 23, 505-11.

Pan CS, Gardner LI, Landsittel DP, Hendricks SA, Chiou SS, Punnett L. Ergonomic exposure assessment: an application of the PATH systematic observation method to retail workers. International Journal of Occupational and Environmental Health 1999; 5:2, 79-87.

Pan CS, Chiou SS, Hendricks S. The effect of drywall lifting method on workers' balance in a laboratory-based simulation. Occupational Ergonomics 2002/2003; 3, 235-49.

Paquet VL, Punnett L, Buchholz B. An evaluation of manual materials handling in highway construction work. International Journal of Industrial Ergonomics 1999; 24, 431-44.

Paquet VL, Punnett L, Buchholz B. Validity of fixed-interval observations for postural assessment in construction work. Applied Ergonomic 2001; 32, 215-24.

Paquet VL, Punnett L, Woskie S, Buchholz, B. Reliable exposure assessment strategies for physical ergonomic stressors in construction and other non-routinized work. Ergonomics 2005; 48:9, 1200-19.

Park JK, Boyer J, Tessler J, Casey J, Schemm L, Gore R, Punnett L. Inter-rater reliability of PATH observations for assessment of ergonomic risk factors in hospital work. Ergonomics 2009; 52:7, 820-9.

RockSteady LLC. http://www.rocksteadyclip.com/ (last accessed on March 1, 2014)

Roebuck JA, Kroemer KHE, Thomson WG. Engineering anthropometry methods. New York: Wiley-Interscience; 1975.

Rosenberg B, Yuan L, Fulmer S. Ergonomics of abrasive blasting: a comparison of high pressure water and steel shot. Applied Ergonomics 2006; 37, 659-67.

Tak S, Punnett L, Paquet V, Woskie S, Buchholz, B. Estimation of compressive forces on lumbar spine from categorical posture data. Ergonomics 2007; 50:12, 2082-94.

Yuan L. Biomechanical analysis of the physical loads on the low back and shoulder during drywall installation. Doctoral Dissertation, University of Massachusetts Lowell, Lowell; 2006.

Yuan L, Buchholz B, Punnett L, Kriebel, D. Estimation of muscle contraction forces and joint reaction forces at the low back and shoulder during drywall installation. Proceedings of the 51st Annual Meeting of Human Factors and Ergonomics Society, Baltimore, MD; 2007.

Yuan L. Validation of an integrated biomechanical modeling approach to the ergonomic evaluation of drywall installation. In *Digital Human Modeling and Applications in Health, Safety, Ergonomics, and Risk Management: Human Body Modeling and Ergonomics (Part II)*, edited by Duffy V, pp. 159-168, Springer-Verlag Berlin Heidelberg; 2013.